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The geochemical evolution of saline groundwater within a fresh water aquifer south of Oakes, North Dakota

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THE GEOCHEMICAL EVOLUTION OF SALINE GROUNDWATER WITHIN A FRESH WATER AQUIFER SOUTH OF OAKES, NORTH DAKOTA

by

David L. Williams

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of the

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in partial fulfillment of the requirements

for the degree of

Master of Science

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1984

This thesis submitted by David L. Williams in partial fulfillment of the requirements for the degree of Master of Science from the University of North Dakota is hereby approved by the Faculty Advisory Committee under whom the work has been done.

Alan E. Kehew
(Chairman)

John R. Reid

This thesis meets the standards for appearance and conforms to the style and format requirements of the Graduate School of the University of North Dakota, and is hereby approved.

Dean of the Graduate School

Permission

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Department Geology

Degree Master of Science

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Signature David L. Williams

Date 11-26-84

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The North Dakota Geological Survey provided field vehicles, silica sand, and cement for the project.

Sigma Gamma Epsilon, Zeta Beta Chapter, awarded funds which were used to purchase tensiometers.

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ABSTRACT

An area of saline/brackish groundwater south of Oakes, North Dakota has been reported by the North Dakota State Water Commission. The concentrated water (over 12,000 mg/L of total dissolved solids) is in direct hydraulic connection with relatively fresh water and shows an abrupt change in concentration and water chemistry between these two end members. The saline/brackish water is beneath a shallow trough or depression which has an approximate area of 6 square miles (15.5 square kilometres). The trough is within the northern part of the Glacial Lake Dakota plain. Sediments in the lake plain, which is an unconfined aquifer, are sands that grade downward to gravels. Within the trough sands are overlain by Holocene lacustrine silts and clays. A discontinuous unit of lacustrine silt lies beneath the upper sand and gravel aquifer. Below both these units is glacial till. Locally, a second sand and gravel aquifer underlies the till. The second aquifer is under confined conditions and is underlain by a second till unit.

In May 1983 observation wells were installed to determine the horizontal extent of the saline/brackish water. In order to determine the vertical extent of that water, and to determine groundwater movement, two detailed traverses of nested piezometers were installed.

Interpretation of hydraulic head data for the two traverses shows a general northerly flow along the N-S traverse and lateral flow along an E-W traverse, toward a central sink. Here, water is assumed to move along the axis of the trough toward the James River. During major recharge events, reversals of hydraulic gradients occur, indicating

outward flow from the center of the depression and downward flow into the lower sand and gravel aquifer. Alternating recharge and stable flow results in relatively stagnant water.

The major constituents of the saline groundwater are Na^+ and SO_4^{2-}; lesser amounts of HCO_3^-, Ca^{2+}, Mg^{2+}; and trace amounts of Fe, Mn, B, F, SiO_2, and Cl^-. Due to the large percentage of carbonates in the aquifer and tills, $CaCO_3$ and $(Ca,Mg)CO_3$ dissolved in the presence of acidified water yield Ca^{2+}, Mg^{2+}, and HCO_3^- ions. Gypsum ($CaSO_4.2H_2O$) yields Ca^{2+} and SO_4^{2-} ions. Pyrite oxidation yields Fe and SO_4^{2-} ions. The tills and surficial clays contain montmorillonite, presumably sodium montmorillonite, which in the presence of Ca^{2+}, exchanges Na^+ for Ca^{2+}. If the system is saturated with gypsum, loss of Ca^{2+} would create an undersaturated condition causing further dissolution of gypsum. Continued Ca^{2+} exchange for Na^+ leads to a dominance of Na^+ and SO_4^{2-} ions.

Evaporation is suggested as the concentrating mechanism within the center of the depression. Mineral precipitation occurs at the water table in surficial clays just below land surface. Major recharge events dissolve the precipitated minerals, move the saline water down to the water table, and then by miscible displacement, transport the denser, saline water to the base of the aquifer. Repeated mineral precipitation and dissolution cycles have led to the concentrated saline/brackish water.

INTRODUCTION

General Statement and Purpose

An area of saline/brackish groundwater in the Oakes aquifer has been reported by the North Dakota State Water Commission one to two miles (1.6 to 3.2 km) south of Oakes, North Dakota. For the most part the saline/brackish water occurs beneath a shallow topographic trough on the Glacial Lake Dakota plain. The Oakes aquifer generally has relatively fresh water, usually less than 500 mg/L total dissolved solids (TDS). Locally, high salinity zones occur which contain water with more than 12,000 mg/L TDS. The majority of people in the area obtain their drinking and irrigation water from the Oakes aquifer (Armstrong, 1980, p.52).

Brackish groundwater was initially discovered by the United States Bureau of Reclamation (USBR) in 130-59-2. Irrigation test wells in the same area revealed that the water quality changed rapidly within a short distance. The subsequent involvement of the North Dakota State Water Commission (NDSWC) and their installation of additional wells divulged the possibility of a fairly large volume of saline/brackish water in the aquifer.

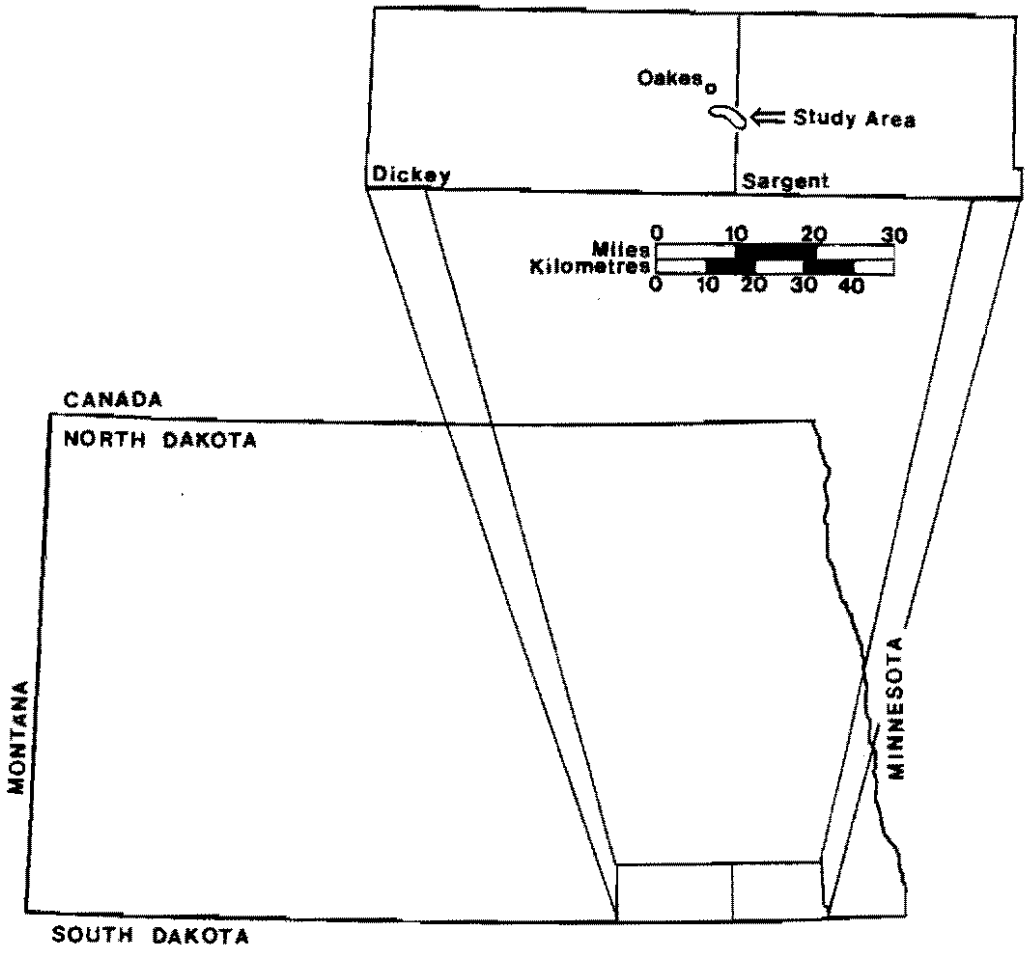
The USBR, Garrison Diversion Unit, is currently building a pumping plant to provide water for a 5,000-acre irrigation test area south of Oakes. The intake canal for the pumping plant, irrigation canals, and drainage pipes either cross or border the saline groundwater area. Possible interaction between the saline/brackish groundwater and irrigation water has raised concern about the vertical and horizontal extent, movement, and quality of the saline water.

The purpose of this project is to characterize the hydrogeologic setting in the area of the saline groundwater and to determine the geochemical origin of this body of saline groundwater.

Location

The study area covers approximately 8 mi^2 (21 km^2) about 2 miles (3.2 km) south of Oakes, North Dakota (Figures 1 and 2). In places, saline groundwater is known to extend outside the study area. These areas were omitted in the interests of brevity and cost after it was determined that they do not have a significant impact upon the outcome of the study.

Figure 1. Location of study area.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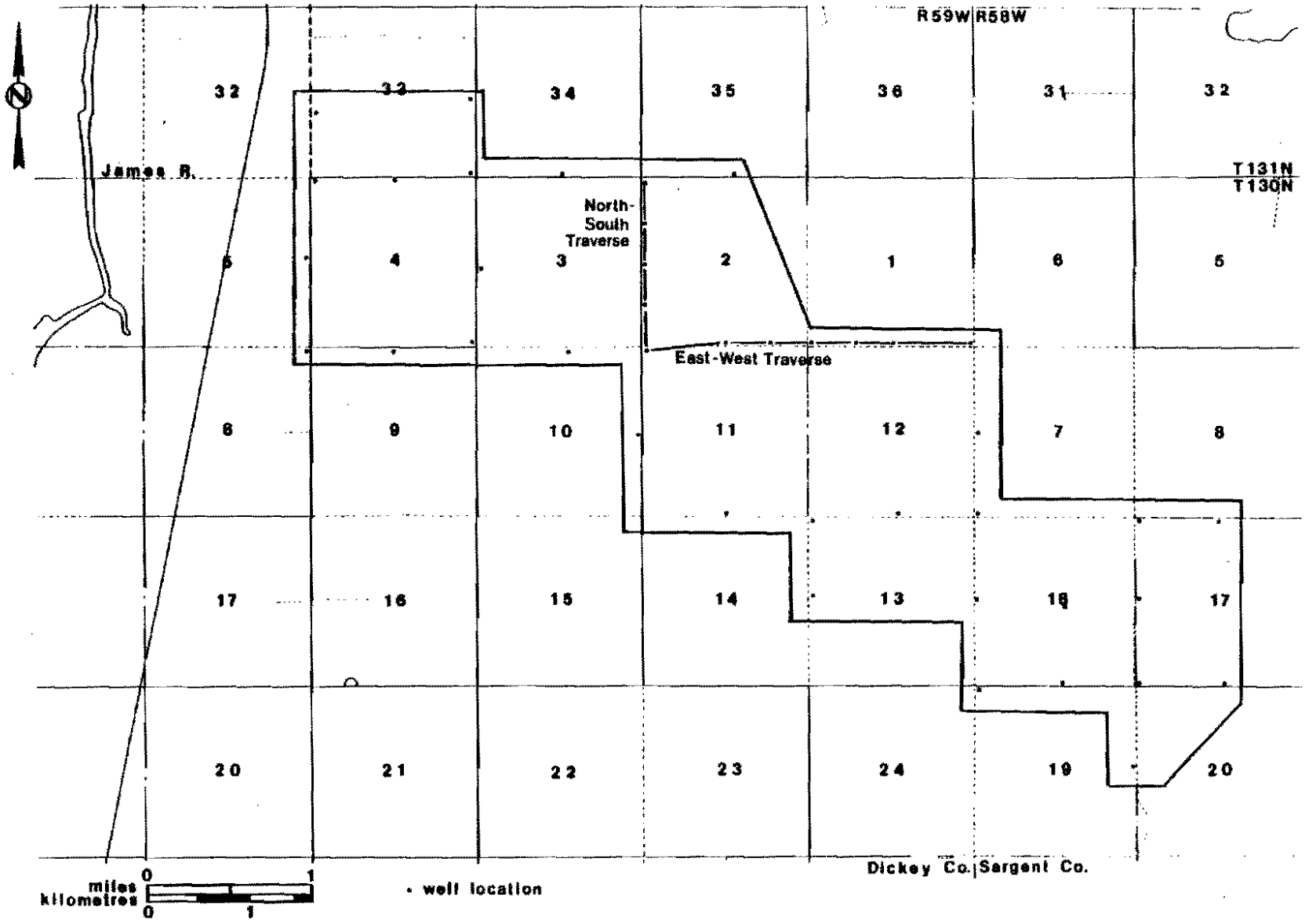
CANADA
NORTH DAKOTA
MONTANA
MINNESOTA
SOUTH DAKOTA

Figure 2. Detailed location of study area.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T131N
T130N
James R.
North-South Traverse
East-West Traverse
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Dickey Co.
Sargent Co.

Objectives

The four specific objectives of the study were to determine:

1) the stratigraphy of sediments in and adjacent to the trough;
2) the groundwater flow system in and around the trough;
3) the three-dimensional relationships between stratigraphy, groundwater quality, and groundwater flow in the saturated zone; and
4) the mineralogical characteristics of the saturated and unsaturated zones.

Previous Work

One of the initial groundwater studies in the State of North Dakota briefly discussed groundwater supplies in the Oakes area (Simpson, 1929). The major groundwater source at that time was the Dakota sandstone, which produced water under artesian conditions.

The first major groundwater study of the Glacial Lake Dakota area was by Rasmussen (1947). The primary thrust was the evaluation of the Oakes aquifer's capacity for large-scale irrigation. Water quality was determined to be very good, with TDS concentrations less than 700 mg/L. Maximum transmissivity (T) for the aquifer was determined to be 10,200 ft^2/day (950 m^2/day).

Armstrong (1980, 1982) determined that the thickness of the Oakes aquifer varies from 2 to 185 feet (0.6 to 56 m). The average thickness ranges from 30 feet (9 m) in Dickey County to 80 feet (24 m) in Sargent County.

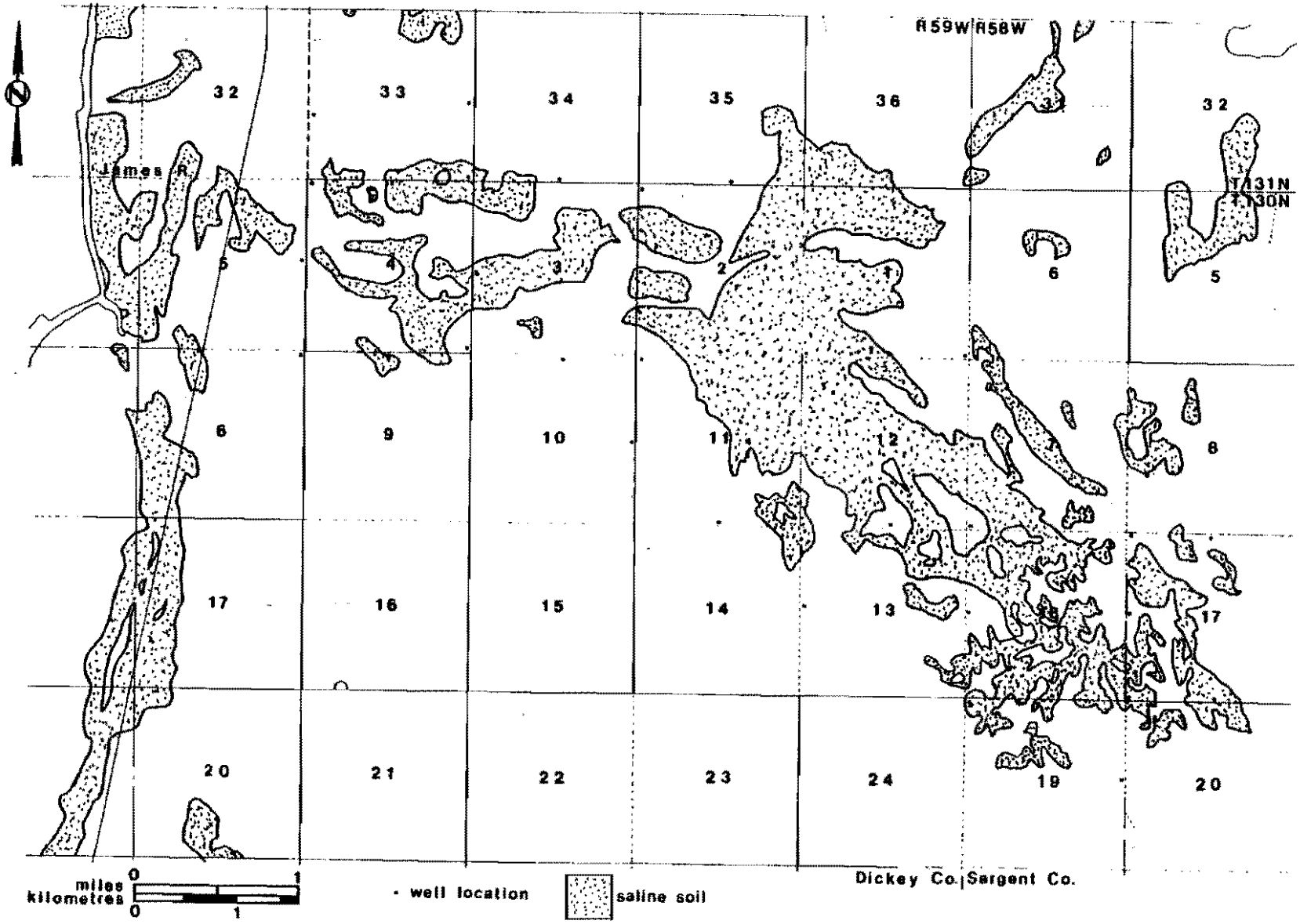
A more recent compilation of data for the Oakes aquifer is available in a series of county reports published cooperatively by the North Dakota Geological Survey and the North Dakota State Water Commission. Armstrong and Luttrell (1978) reported concentrations ranging from 293 to 798 mg/L TDS and a maximum transmissivity of 13,800 ft^2/day (1,280 m^2/day) in Dickey County. In Sargent County, Armstrong (1982) estimated the maximum transmissivity values to be 20,000 ft^2/day (1,900 m^2/day). He attributed the increase in transmissivity there to increased aquifer thickness.

The Oakes aquifer is recharged by direct infiltration of precipitation and snowmelt (Armstrong, 1980). Possible leakage into the Oakes aquifer from the underlying Spiritwood aquifer may occur through the intervening till. Discharge from the Oakes aquifer occurs by evapotranspiration, pumpage, leakage into the Spiritwood aquifer, and groundwater flow to the James River (Armstrong, 1980).

Soil surveys in the study area show extensive saline soils (Larsen, et al., 1964, and Thompson and Sweeney, 1971). Saline soils (Figure 3) imply groundwater discharge (Buckman and Brady, 1969, p. 341).

The earliest description of the geology of the Glacial Lake Dakota deposits was by T. C. Chamberlin (1883). Along with the study of the groundwater of the Oakes aquifer, Rasmussen (1947) described the geologic history of Glacial Lake Dakota. Brophy (1961) gave a detailed description of the geologic history of Glacial Lake Dakota within the Oakes area. The most recent report on the geology of the Oakes area was by Bluemle (1979a, 1979b).

Figure 3. Saline soils south of Oakes, North Dakota (from Larsen, et al., 1964, and Thompson and Sweeney, 1971).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well location
saline soil
Dickey Co.
Sargent Co.

Local Geologic Setting

Bedrock Geology

The uppermost bedrock in the Oakes area is the Cretaceous Niobrara Formation (Bluemle, 1979a) (Figure 4). Approximately 8 to 10 miles (13 to 16 km) north of Oakes, the Pierre Formation overlies the Niobrara Formation (Armstrong, 1980, p.24) The Niobrara Formation is calcareous shale, whereas the Pierre Formation is non-calcareous shale. The basal member of the Pierre Formation contains beds of gypsum and anhydrite (Gill and Cobban, 1965). Entrainment of gypsum and anhydrite by the late Wisconsinan glacier may be responsible for the occurrence of sulfates in the tills of the Oakes area.

Pleistocene Geology

Previous studies of the Oakes aquifer have determined that the sediments were deposited in a proglacial lake in contact with the late Wisconsinan glacier (Bluemle, 1979a). The proglacial lake was named Lake Dakota because it extended into both North and South Dakota (Flint, 1971, p. 565). At its maximum extent, the lake was nearly 100 miles (161 km) long with its head just north of Oakes, North Dakota. The lake was confined to the east and west by ice or till, on the north by ice, and on the south by a natural topographic high.

The resulting lacustrine sediments grade from gravel, and coarse to fine sand (the Oakes aquifer), at the north end of the lake plain, to silt near the South Dakota border. Beneath the lacustrine sand of this aquifer lie, from top to bottom, a discontinuous lacustrine silt, a till

Figure 4. Stratigraphic column for Dickey and LaMoure Counties (from Bluemle,1979a, p.7).

AGE	UNIT NAME		DESCRIPTION	THICKNESS (feet)
Quaternary	Oahe Formation (Holocene)		Sand, silt, and clay	?
	Coteharbor Group (Pleistocene)		Till, sand, gravel, silt, and clay	0- 600
Tertiary				Absent
Cretaceous	Pierre Formation		Shale	1,200- 1,800
	Niobrara Formation		Calcareous shale	
	Carlile Formation		Shale	
	Greenhorn Formation		Calcareous shale	
	Belle Fourche Formation		Shale	
	Mowry Formation		Shale	0- 420
	Newcastle Formation		Sandstone	
	Skull Creek Formation		Shale	
	Fall River Formation		Sandstone and shale	100- 300
	Lakota Formation		Sandstone and shale	
Jurassic	Morrison Formation		Siltstone and claystone	0- 150
Triassic				Absent
Permian				
Pennsylvanian				
Mississippian	Madison Formation		Limestone	0- 350
Devonian	Duperow Formation		Dolomite and shale	0- 75
Silurian				Absent
Ordovician	Red River Formation		Limestone and dolomite	0- 550
	Winnipeg Group	Roughlock Formation	Shale and siltstone	0- 220
		Icebox Formation	Shale	
		Black Island Fm.	Sandstone	
Cambrian	Deadwood Formation		Sandstone and limestone	0- 90
Precambrian basement rocks			Schist and granite	—

unit, a second sand and gravel aquifer, and a second till unit (Figure 5). The Spiritwood aquifer, which is known to exist north of the area, may have an hydraulic connection with the second sand and gravel aquifer.

On the basis of the lithologic logs obtained in this study, the till unit which occurs at the surface on the eastern side of the lake plain, appears to be the same till unit that underlies the Oakes aquifer (Figure 5). The till hills to the east, called the Lake Oakes Hills, are interpreted to have contained a proglacial lake, Lake Oakes (Nielsen, 1973, p.49-51). Lake Oakes and Lake Dakota were later overidden by a subsequent advance of the Wisconsinan ice.

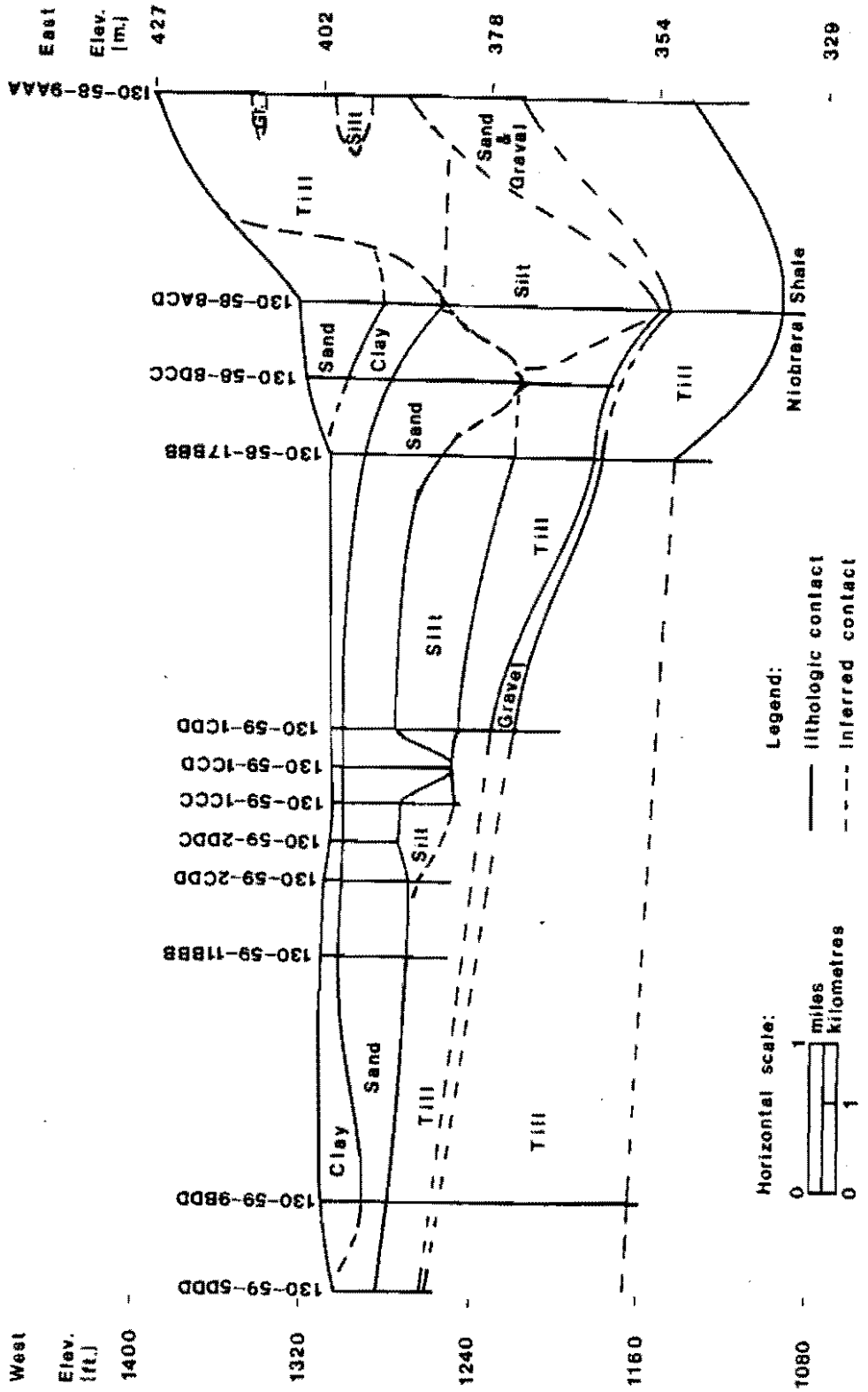
Holocene Deposits

Overlying the lacustrine sediments of Lake Dakota is a discontinuous cover of Holocene wind-blown sand (Bluemle, 1979a). Numerous dunes and blowouts occur on the lake plain. The largest, up to 40 feet (12 m) high, lies along the eastern edge of the lake plain. Holocene alluvium and colluvium partially fill the James River Valley.

Topographic Setting

The topography of the area was initially described by Brophy (1961) as an inconspicuous series of low ridges extending northwestward from 130-59-13. The ridges further split into several distinct ridges in

Figure 5. Stratigraphy of Holocene, Pleistocene, and Cretaceous sediments south of Oakes, North Dakota. For location of cross-section see Figure 6.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1240
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130-58-8ACD
130-58-8DCC
130-58-17BBB
130-59-1CDD
130-59-1CCD
130-59-1CCC
130-59-2DDC
130-59-2CDD
130-59-11BBB
130-59-9BDD
130-59-5DDD
Till
Silt
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Sand
Clay
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Niobrara Shale
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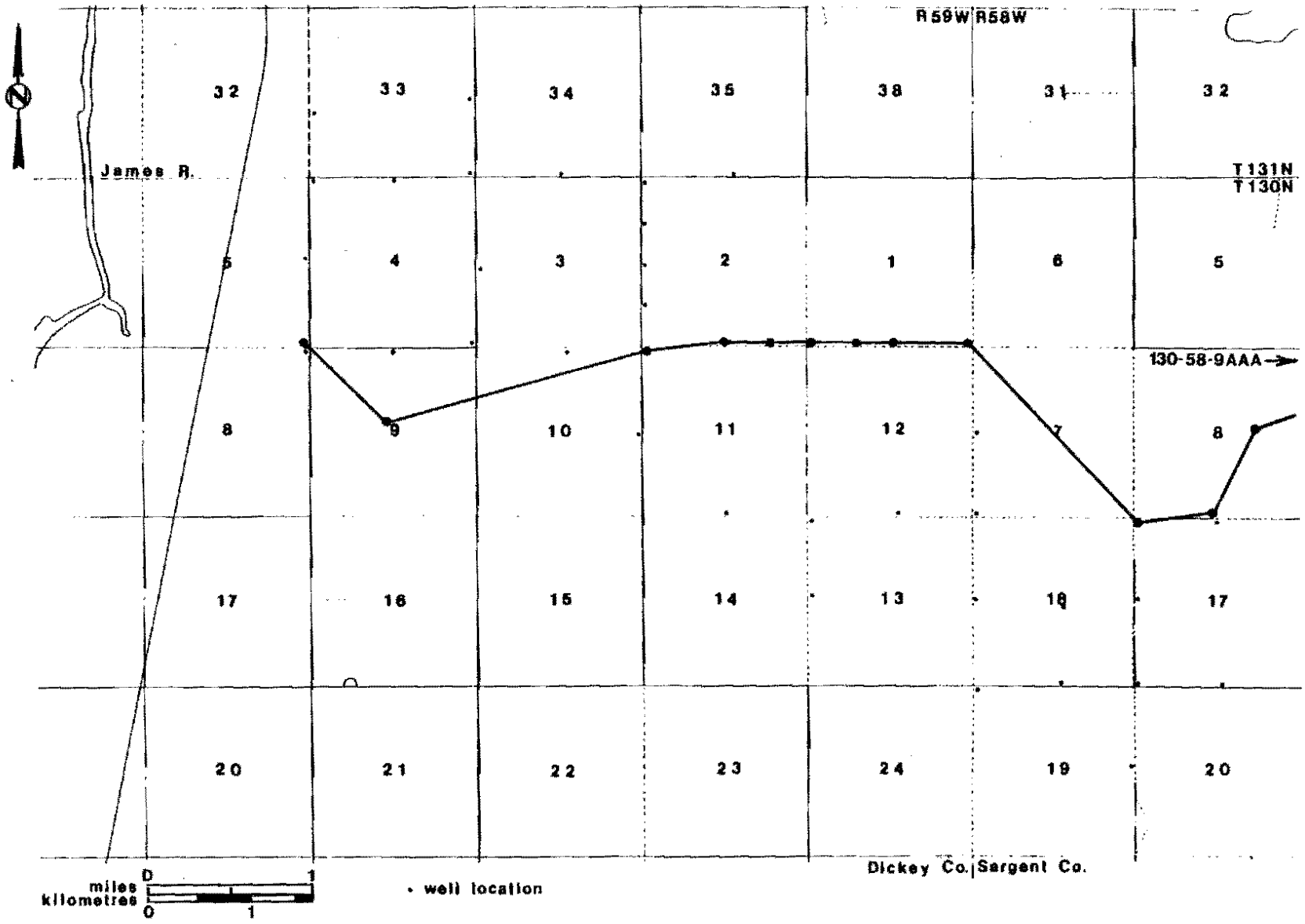
inferred contact
Horizontal scale:
miles
kilometres

Figure 6. Traverse location for cross-section in Figure 5.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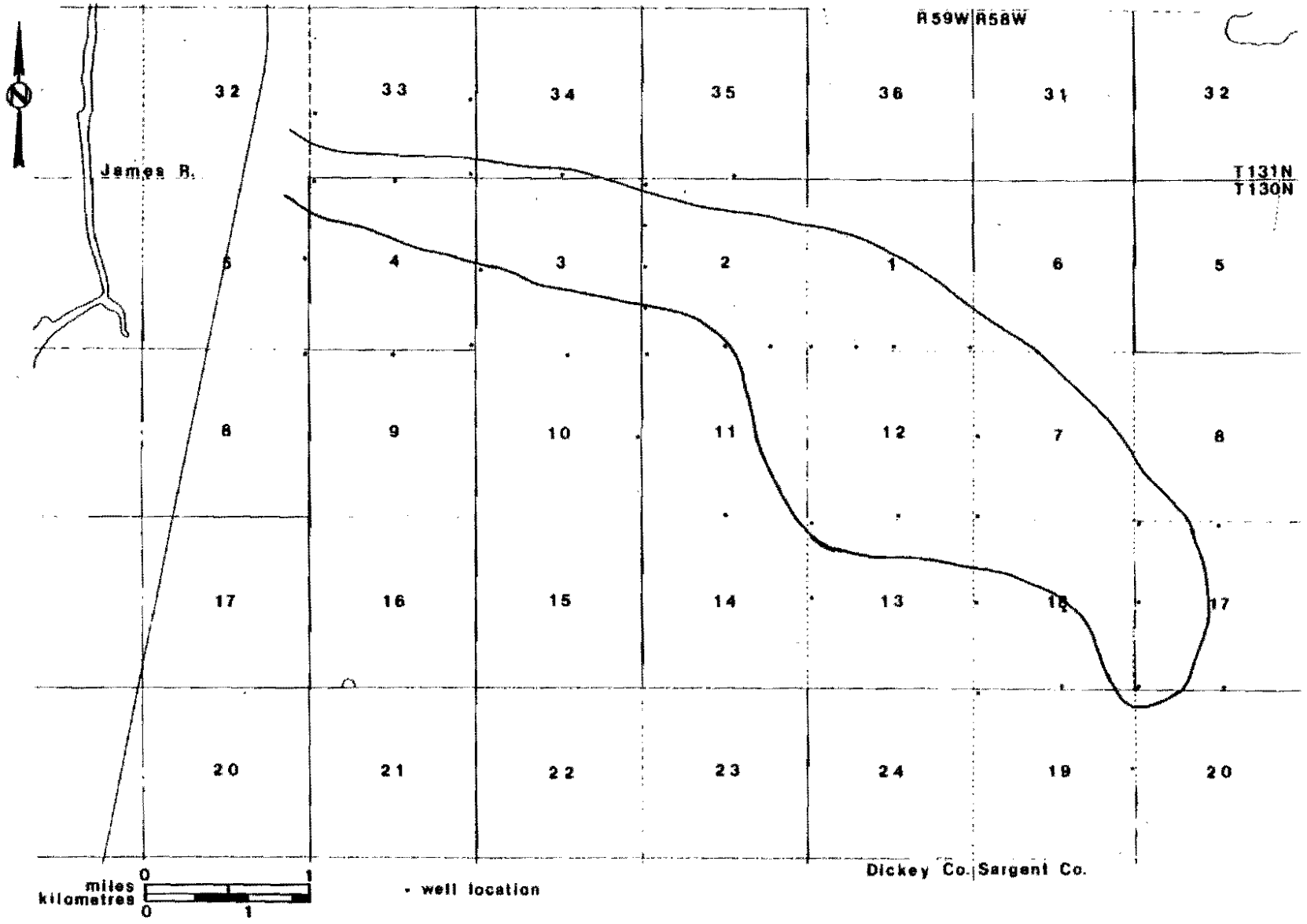
130-59-3 and 130-59-10. North of the ridge in 130-59-13 is a shallow depression under which the saline groundwater is located. The depression, very broad in sections 1, 2, 11, and 12 in 130-59 and sections 7, 8, 17, and 18 in 130-58, narrows to the northwest (Figure 7). The depression extends northwest through sections 2, 3, and 4 of 130-59 and sections 32, 33, and 34 of 131-59. It is visible, in cross-sectional view, from the floodplain of the James River looking east toward 131-59-32D

Recent Fluctuations in Lake Level

Local residents report the depression to be a pluvial lake. William Johnson (1983, farmstead located at 131-59-1D) described the depression to have been a lake in 1916. Later, (no date given) the lake dried up. In the 1940's the depression was again a lake. Johnson states the lake in 1949 was over a thousand acres ($4X10^6$ m^2) in area with a depth of at least 5 feet (1.5 m). In December of 1949 Johnson, while trapping muskrat, broke through the ice and fell into water up to his neck. In recent years the lake basin has been dry.

The pluvial nature of the depression was also evident in the spring of 1984. On March 29, 1984, while obtaining water levels from wells along the southern part of 130-59-1 and 130-59-2, I walked a quarter of a mile through knee-deep water. The area of the lake was estimated to have been nearly 1 mi^2 (2.59 km^2). The lake level decreased from March 29, 1984 to May 15, 1984 until only small pockets of water remained in the lower areas.

Figure 7. General outline of the topographic depression.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Sargent Co.

METHODS

Location-numbering System

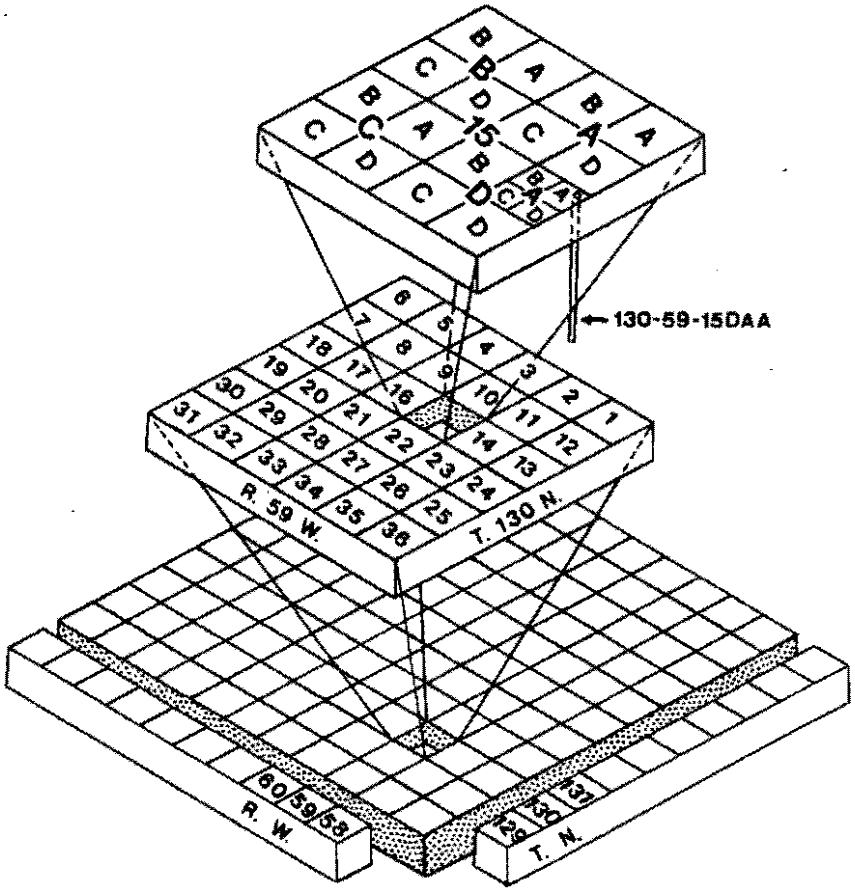
A location-numbering system, used by the United States Geological Survey (Armstrong, 1982), will be followed in this paper (Figure 8). The first number of the well designation refers to the township, the second refers to the range, and the third refers to the section in which the well is located. The letters A, B, C, and D denote respectively, the northeast, northwest, southwest, and southeast quarter section, quarter-quarter section, and quarter-quarter-quarter section. For example, 130-39-15DAA would be in the NE1/4 NE1/4 SE1/4 section 15, T.130N., R59W.

Field

Instrumentation

Initial delineation of the horizontal and vertical distribution of the saline groundwater required installation of observation wells throughout the area. The well sites were selected in and around the depression containing the saline groundwater. Water samples were

Figure 8. Location-numbering system (from Armstrong, 1982).


130-59-15DAA
R. 59 W.
T. 130 N.
R. W.
T. N.

collected both from the newly installed observation wells and existing USBR wells. Chemical analyses of water samples were used to determine the horizontal extent of the saline/brackish water. To determine the vertical extent of that water and the direction of groundwater movement, two traverses of nested piezometers were installed (Figure 2).

The observation wells, installed during May, 1983, were constructed of two-inch (5.08 cm) diameter PVC pipe cemented to 1.5 inch (3.81 cm) diameter, number 10 slot PVC screens, 1.0 foot (0.3 m) in length. A foot-valve was attached to the base of the screen. Holes for the observation wells were drilled using a truck-mounted auger and a crew from the USBR. Observation well installation consisted of: (1) augering a hole to the desired depth; (2) dropping the PVC pipe into the hole, screen first; (3) attaching a hose to the top of the pipe and jetting water into the well (this was necessary due to a partial collapse of the hole after removal of the auger); (4) forcing the pipe down the hole to the desired depth as the sediments were churned up by the injected water; (5) placing two shovels full of bentonite or cement on top of the sand in the annulus; (6) backfilling with cuttings and gravel; (7) pumping the well for a calculated period of time to remove the drilling water introduced during the jetting process; and (8) covering the well with a plastic screw cap.

The difficulty in obtaining a grout seal directly above the screen prevented the observation wells from being used as piezometers but did permit their use as water-table wells. The bentonite or cement used in the upper part of the hole prevented the water around the screen from being contaminated by surface water.

Piezometers were installed during August, 1983. The piezometers were constructed of two-inch (5.08 cm) diameter PVC pipe cemented to 1.25 inch (3.18 cm) diameter, number 18 slot PVC screens usually 1 foot (0.3 m) in length. Small centralizer fins were cemented to the screens to insure centering in the holes. Check-valves were attached to the base of the screens. Holes for the piezometers were drilled using a forward mud rotary drill rig and a crew from the NDSWC. Piezometer installation consisted of: (1) drilling the hole to the desired depth; (2) dropping the PVC pipe into the hole, screen first; (3) backwashing of water from the water truck through the well to clean the screened interval of mud and cuttings; (4) washing silica sand down a 1.25 inch (3.18 cm) diameter tremie pipe placed beside the piezometer (this was done to assure that the sand surrounded and covered the screen to the top); (5) pouring a cement slurry down the same tremie to cap the sand pack; (6) backfilling with cuttings to the surface the day after the cement was emplaced; (7) pumping with air compressors for a calculated period of time to remove the water introduced in the drilling process; and (8) covering the pipe with a plastic screw cap.

The piezometers were installed in nests to delineate the vertical and horizontal distribution of hydraulic head along two perpendicular traverses. A typical nest of piezometers consisted of a water-table well, a piezometer near the base of the Oakes aquifer, and a piezometer screened in the underlying till. The north-south traverse was one mile (1.61 km) in length and along the western edge of 130-59-2 (Figure 2). The east-west traverse was two miles (3.22 km) in length and located along the southern edge of 130-59-1 and 130-59-2. The two traverses shared a nest of piezometers at 130-59-11BBB (Figure 2).

A nest of two tensiometers was installed at 130-59-1CCC on July 19, 1983 and operated until September 28, 1983. At that time the tensiometers were removed to prevent damage from freezing. They were reinstalled April 23, 1984 at 130-59-1CDD and operated until June 4, 1984. The two tensiometers were installed at different depths: one at 36 inches (91.4 cm) and one at 60 inches (152.4 cm). The 60-inch tensiometer could only be inserted to 52 inches (132 cm) from the surface in 1984.

Tensiometers measure the tension head or suction head in the unsaturated zone (Freeze and Cherry, 1979, pp. 39-41). The hydraulic head can be determined by adding the negative (less than atmospheric) tensiometer head value to the elevation at the point of measurement.

Precipitation was collected in a plastic, wedge-shape rain gauge supplied by one of the local implement dealers. The rain gauge was mounted at the top of a fence post within 20 feet (6.1 m) of the tensiometers. Both precipitation and tensiometer data were collected by USBR personnel for this study.

Sediment Description

Lithologic samples were collected and described during observation well and piezometer installation. Sediment texture, color, mineralogy, and depth were recorded (Appendices A and B). Samples were placed in labeled bags and returned to the laboratory for further analysis.

Water Level Readings

Monthly water levels were measured from the observation well and piezometer network using a battery-powered water level monitoring tape. Prior to determination of the hydraulic head data, well top elevations (in feet above sea level) were determined by a USBR survey crew.

During the winter, snow drifts made it impossible to drive to the well sites in the center of the depression. The USBR provided a snowmobile and driver during this time. During the spring thaw in March, water levels were not measured in some wells due to the amount of water ponded within the depression.

Hydraulic Conductivity Estimates

The method used to estimate hydraulic conductivity was the single-well response test (Hvorslev, 1951). For this, a solid cylinder was dropped rapidly into a 2-inch (5.08 cm) diameter well, raising the water level exactly 3.74 feet (1.14 m) (slug test). The recovery of the water level with respect to time is proportional to the hydraulic conductivity. After the water level reached equilibrium after a slug test, the cylinder was removed rapidly, thereby lowering the water level (bail test). The hydraulic conductivities (Appendix C) were computed using parameters obtained from a linear regression program written for a programmable calculator.

Water Sampling Procedure

Water sampling was accomplished using a specially equipped van provided by the North Dakota Mining and Mineral Resources Research Institute (NDMMRRI). Water samples were collected from the observation wells in May-June, 1983 and from the piezometers in September, 1983. Samples were collected from both the observation wells and piezometers in October-November, 1983 and February and April, 1984.

Water samples were collected from the wells by a variety of methods: bailing, air lift, submersible pump, and centrifugal pump. The sampling method is noted on each well chemistry report (Appendix D). Difficulty in obtaining a sample from the 1.25-inch (3.2 cm) screens of the NDSWC water-table wells with the air lift or centrifugal pump methods necessitated the constuction of a 0.75-inch (1.9 cm) bailer. The bailer was 20 feet (6.1 m) in length and was constructed using a marble as the ball in the foot valve. The water sample was removed by inserting a pencil into the foot valve to unseat the marble. To be certain the water sample that was collected was representative of the formation water, approximately 2.5 well volumes were withdrawn prior to sampling.

Immediately after sampling, pH was determined with a Hach model 1975 pH meter; conductivity (micromhos/cm) was determined with a Horizon, model 1484-10, conductivity meter; temperature was measured in degrees celsius; and comments regarding the samples were recorded. Water samples were then filtered through 8 micron and 0.45 micron, 142 mm diameter, filters. Three samples were collected: 250 ml raw; 500 ml filtered; and 500 ml filtered and acidified with nitric acid. After

bottling, the samples were shipped to the NDSWC laboratory in Bismarck for analysis. Because the NDSWC laboratory does not have refrigeration facilities the samples were not refrigerated during shipping.

Difficulty in obtaining water samples from some wells was encountered during the study period. Wet fields and snow prevented access to some wells with the sampling equipment. The missing water data are noted in Appendix D with a dashed line.

Laboratory

Textural Analyses

Sediments collected during observation well installation were analyzed by the USBR (Appendix E). Textural analyses of sediments from the NDSWC wells are included in Appendix F.

Mineralogical Analyses

Mineralogical analyses of selected samples were completed by the NDMMRRI Natural Materials Analytical Laboratory (NMAL) to relate sediment mineralogy to water chemistry. Initially, clay-rich sediments from the upper clay unit were processed by a depth-settling time method to obtain less than 4 micron diameter sediments (Folk, 1974, p. 40). After a specified time, the less than 4 micron slurry was pipetted onto a carbon disc and air dried. A mineralogical analysis, obtained from a

Phillips X-Ray Diffractometer (XRD), produced only quartz, calcite, and gypsum peaks. It was assumed that the high salinity of the sediments caused flocculation of the clay minerals, preventing their detection. To bypass the salinity problem, bulk sediment analysis samples were prepared by crushing the sample with a mortar and pestle until the sample was finely ground into a powder. The powder was top-loaded into the XRD and analyzed.

Computer Analysis

The WATEGM-SE chemical equilibrium computer program (Palmer, 1983) was employed to determine mineral saturation indices. XRD methods detected a mineral (siderite) which forms under reducing conditions. Because the reduced ionic form of iron was present, it was then necessary to use the reduced forms of iron and manganese in the program. Although oxidizing conditions were assumed to exist at the surface, the reduced forms in the program were determined to give a more accurate account of the mineralogy present.

Contour Mapping

Chemical data (TDS and mineral saturation indices) and physical data (hydraulic head and water table) were plotted on base maps of the study area and cross-sections along the two traverses. Plots of data from each water-table measurement period and each water sampling interval were prepared to illustrate seasonal changes in groundwater chemistry and flow characteristics.

RESULTS

Sediment Lithology and Mineralogy

Surficial Unit

The uppermost stratigraphic unit of the depression is clay of variable thickness and texture. Along the north-south traverse, the clay unit thickens toward the center of the trough (Figure 9). In contrast, the thinnest clay deposits lie at the center of the east-west traverse (Figure 10). The thickest clay is near the eastern edge of the depression at 130-58-17BBB, where 16.5 feet (5.0 m) of clay are present (Figure 11).

Textural analyses indicate the surficial material ranges from almost all clay to loam. The upper 4 feet (1.2 m) of this unit consists of a discontinuous layer of sandy loam, which local residents report was deposited in the 1930's. Moving downward, a silty loam is encountered and beneath that is clay. The sequence varies and at some sites either the sandy loam, silty loam, or the clay may be absent.

Color variations within the clay are most likely caused by the oxidation of the sediments and the precipitation of calcite and gypsum.

Figure 9. North-south traverse stratigraphy. See Figure 2 for location of cross-section.

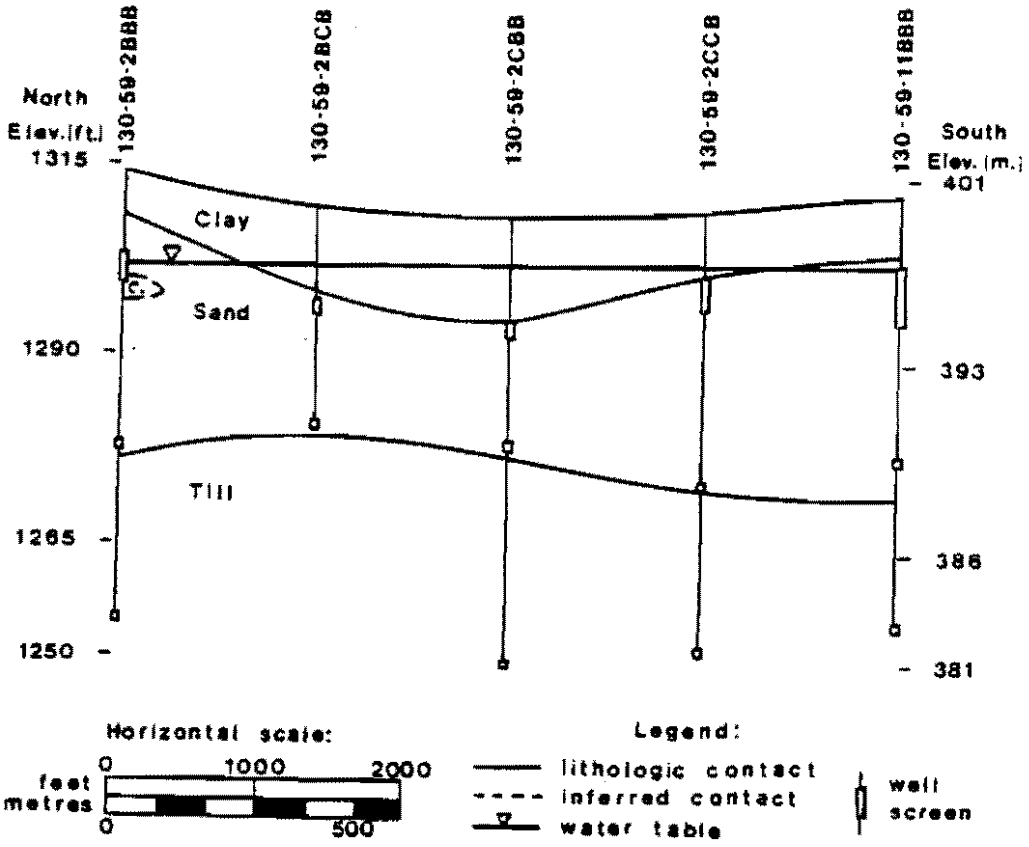

North
Elev.(ft.)
1315
1290
1265
1250
130-59-2BBB
130-59-2BCB
130-59-2CBB
130-59-2CCB
130-59-11BBB
South
Elev.(m.)
401
393
386
381
Clay
Sand
Till
Horizontal scale:
feet
metres
0
1000
2000
500
Legend:
lithologic contact
inferred contact
water table
well screen

Figure 10. East-west traverse stratigraphy. See Figure 2 for location of cross-section.

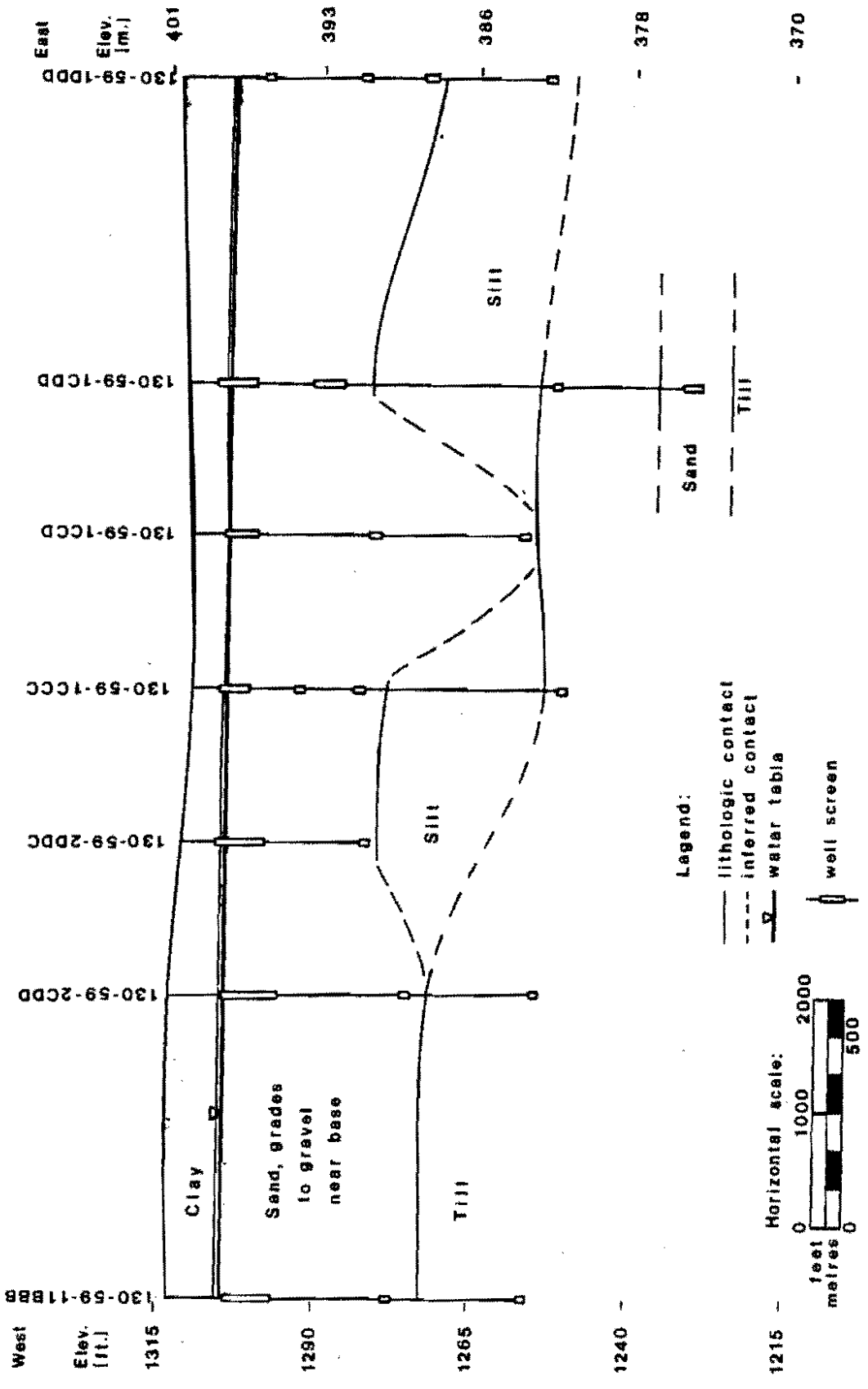
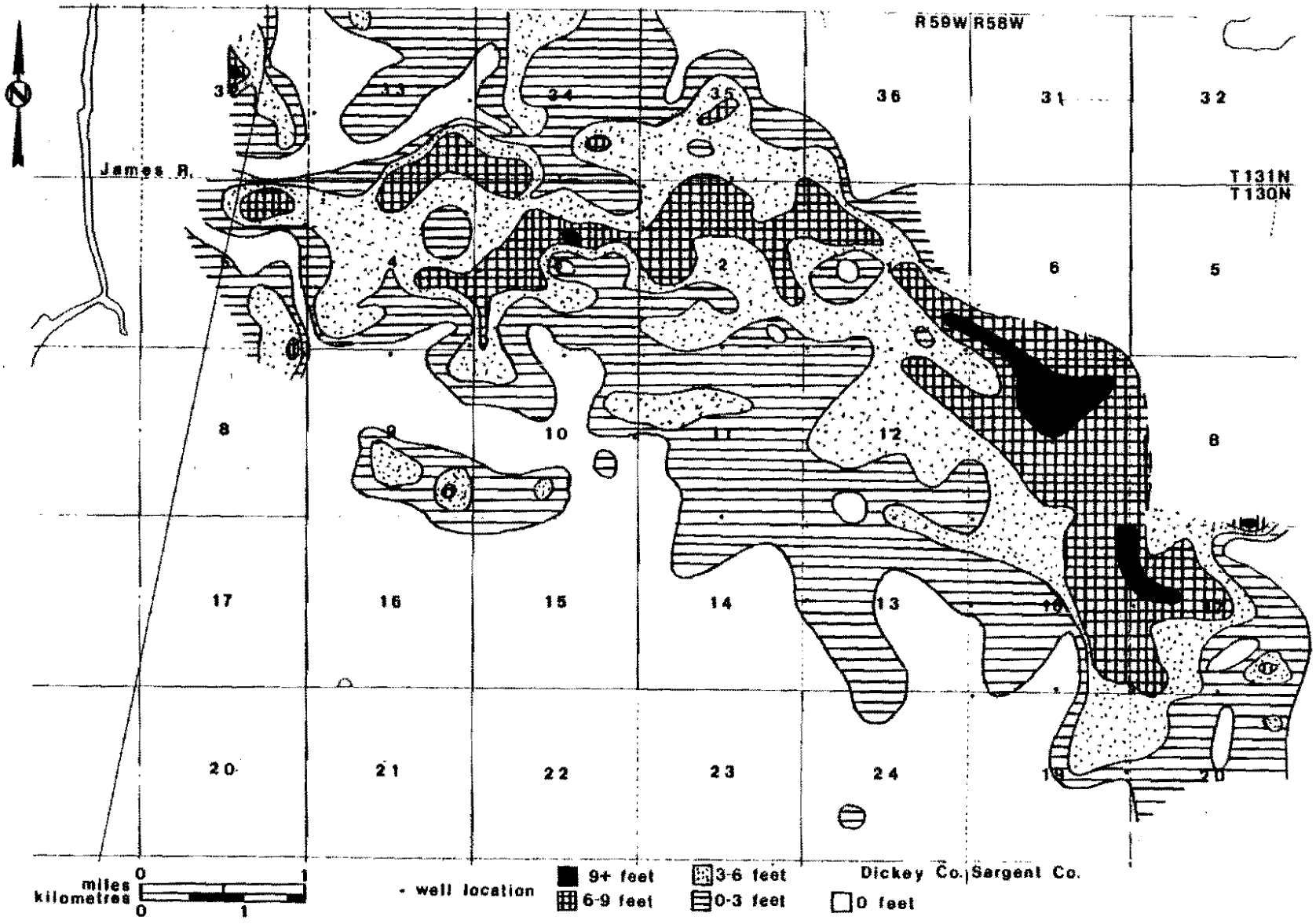

East
Elev. (m.)
401
393
386
378
370
130-59-1DDD
130-59-1CDD
130-59-1CCD
130-59-1CCC
130-59-2DDC
130-59-2CDD
130-59-11BBB
West
Elev. (ft.)
1315
1290
1265
1240
1215
Clay
Sand, grades to gravel near base
Till
Silt
Sand
Till
Legend:
lithologic contact
inferred contact
water table
well screen
Horizontal scale:
0
1000
2000
feet
0
500
metres

Figure 11. Surficial clay/silt isopach map. Data from USBR Detail Land Classification Maps (1957, 1958, 1969, 1979, 1980).


R59W R58W
James R.
T131N
T130N
Dickey Co.
Sargent Co.
miles
kilometres
0
1
0
1
- well location
9+ feet
6-9 feet
3-6 feet
0-3 feet
0 feet

The surficial clays are brown to light brown in the oxidized zone whereas the lower clays (below the water table) are gray to dark gray in the reduced zone. Precipitated calcite colors the sediments a white-gray shade.

Mineralogical characteristics of the surficial material vary with depth and location (Table 1). The clay minerals determined by XRD analysis are: montmorillonite, muscovite/illite, chlorite, and kaolinite. Other minerals detected were: quartz, plagioclase, gypsum, and calcite. The difficulty in obtaining less than 4 micron diameter clays prevented the differentiation of sodic and calcic montmorillonitic clays. Individual selenite (gypsum) crystals were observed in the thicker clays (130-58-17BBB, USBR well#204, Appendix A).

Snail shells also occur in the surficial clay unit. A 4.8 lb (2.2 kg) auger sample, obtained from the upper 3 feet (0.9 m) at 130-58-7CCC, was soaked in a 4% calgon solution. Dispersion of the sediments and rinsing produced 3 in^3 (50 ml) of shell fragments.

Oakes Aquifer Unit

The Oakes aquifer exhibits textural and lithologic changes downward through the unit, varying from a very fine- to very coarse-grained sand to gravel. Generally the sand coarsens near the base of the aquifer. The alternation of fine-grained and coarse-grained sands, as observed at 130-59-12DCC (USBR well# 212, Appendix A), reflects variations in depositional energy.

The mineralogy of the sand unit is fairly uniform. The major minerals, as determined by XRD, are: quartz, plagioclase, calcite, and

Table 1

Mineralogical Analyses

by X-Ray Diffraction

LOCATION	DEPTH	LITHOLOGY	Mo	Mu/I	Ch	K	Q	P	Gy	Ca	D	S	Go
130-58-7CCC	10-46 in.	Sur. Cl.	X	X	X		X	X		X	X		
130-58-18AAA	20-36 in.	*Sur. Cl.					X		X	X			
130-58-18AAA	75-85 in.	*Sur. Cl.					X		X				
130-58-18AAA	110-120 in.	Sur. Cl.	X	X	X	X	X	X					
130-58-18ADD	50-110 in.	*Sur. Cl.					X						
130-58-18BCC	8-8.5 ft.	Sh. S.	X	X	X		X	X		X	X		X
130-58-19ADD	15.5-16.5 ft.	Sand					X	X		X	X		
130-59-1CCC	41-45 ft.	Silt					X	X	X	X	X		
130-59-1CCC	56-60 ft.	Till	X	X	X	X	X	X		X	X	X	
130-59-1DDD	42-44 ft.	Nodule					X		X				
130-59-2CDD	51-55 ft.	Till	X	X	X	X	X	X		X	X	X	
130-59-2DDD	25-32 in.	Sur. Cl.					X	X		X			
130-59-12DCC	13.5-14 ft.	Sand					X	X		X	X		
130-59-12DCC	33.5-34 ft.	Sand					X	X		X	X		

KEY:

Mo = Montmorillonite
Mu/I = Muscovite/Illite
Ch = Chlorite
K = Kaolinite
Q = Quartz
P = Plagioclase
Gy = Gypsum
Ca = Calcite
D = Dolomite
S = Siderite
Go = Goethite
Sh. S. = Shaly Sand
Sur. Cl. = Surficial clay/silt
* = Samples were prepared by pipette, all others were powdered

Conversion factors: 1 inch = 2.54 cm, 1 foot = 0.3048 m

dolomite (Table 1). Occasionally, discontinuous layers of shaly and lignitic sands are distributed throughout the aquifer (Appendices A and B). Sand-size lignite particles suggest the meltwater from the Wisconsinan glacier did not transport the friable lignite very far. The shaly sands contain montmorillonite, muscovite/illite, chlorite, quartz, plagioclase, calcite, and dolomite. The individual determination of muscovite and illite cannot be distinguished easily by bulk XRD methods. Although individual shale particles were non-calcareous, driller's logs, from the NDSWC, report the Niobrara Formation in the Oakes area to be a calcareous mudstone which contains white specks. It is therefore assumed that the shale particles in the aquifer were derived from the Pierre Formation, a unit that consists of montmorillonite, illite, chlorite, and kaolinite (Tourtelot, 1962). Shale mineralogy is important because of the potential for cation exchange on clay minerals. It should also be noted that goethite, indicative of oxidizing conditions, was identified on sand grains obtained from a depth of 8 to 8.5 feet (2.4-2.6 m).

Silt Unit

A discontinuous silt unit lies beneath sands of the Oakes aquifer (Figure 10). The silt unit, encountered only along the east-west traverse, is characterized as a laminated olive-gray, pebbly, sandy, clayey silt. The unit may have been deposited within a supraglacial lake. The maximum measured thickness of the silt unit is 27 feet (8.2 m).

The mineral composition of the silt includes quartz, plagioclase, calcite, dolomite, and gypsum (Table 1). The pebbles found within the silt are carbonates and crystalline rocks. Intergrown gypsum nodules, concentrated near the top of the unit occur from 130-59-1CCC to 130-59-1DDD along the east-west traverse.

Till Unit

Till directly underlies the Oakes aquifer and the silt unit (Figure 10). The till is texturally variable but generally can be characterized as an olive-gray, pebbly, bouldery loam. Till thicknesses vary from 25-80 ft. (7.6-24 m) within the study area.

Bulk till samples from the east-west traverse indicate a composition of montmorillonite, muscovite/illite, chlorite, kaolinite, quartz, plagioclase, calcite, dolomite, and siderite (Table 1). Gypsum nodules are present, but less abundant than in the overlying silt.

Beneath the till is a second sand and gravel aquifer which may have an hydraulic connection with the Spiritwood aquifer. Beneath the second sand and gravel aquifer is another till unit. Samples from the lower aquifer and till units were not obtained. The well in the lower aquifer, at 130-59-1CDD, was installed by the NDSWC on July 9, 1982 before the study began.

Precipitation

Prior to July 19, 1983 the area received a large, but unknown amount of rain from a series of thunderstorms. Precipitation amounts for the remainder of the summer of 1983 and the spring of 1984 are listed in Tables 2 and 3, respectively. In addition to the precipitation amounts reported in Table 3, 3.4 inches (8.6 cm) of water equivalent precipitation was noted in the rain gauge from February 25 through April 25, 1984. The total precipitation from February 25 through June 4 was over 10.2 inches (25.9 cm).

Subsurface Water Occurrence and Flow

Moisture Conditions in the Unsaturated Zone

Hydraulic heads in the unsaturated zone were monitored using a nest of two tensiometers. Precipitation, tensiometric head, and water levels for July 19, 1983 through September 28, 1983 and April 18, 1984 through June 4, 1984 are listed in Tables 2 and 3, respectively.

The tensiometers were initially emplaced at 130-59-1CCC on July 19, 1983. After the mid-July rainfall both tensiometer readings had almost identical unsaturated hydraulic heads, indicative of uniform moisture conditions (Figure 12). After July 19, the 36-inch tensiometer measured a lower hydraulic head than the 60-inch tensiometer until September 28, 1983, after which they were removed for the winter. The lower hydraulic head at the 36-inch level is indicative of an upward gradient.

Table 2
PRECIPITATION, TENSIOMETRIC HEAD,
AND HYDRAULIC HEAD
AT
130-59-1CCC

Date 1983	Prec. inches	36 in. tens. a.s.l.	60 in. tens. a.s.l.	Water table well a.s.l.	16 ft. well a.s.l.	29 ft. well a.s.l.	60 ft. well a.s.l.
7-19	-	1297.7	1297.9	NA	1302.7	1302.7	NA
7-25	-	1296.1	1297.9	NA	-	-	NA
8-1	-	1294.1	1297.9	NA	-	-	NA
8-2	0.10	1291.6	1297.7	NA	-	-	NA
8-3	-	1290.9	1297.7	NA	-	-	NA
8-4	-	1289.4	1297.7	NA	-	-	NA
8-5	-	1287.8	1297.7	NA	-	-	NA
8-8	-	1282.9	1297.5	NA	-	-	NA
8-9	trace	1282.1	1297.5	NA	-	-	NA
8-10	-	1281.1	1297.7	NA	-	-	NA
8-11	-	1280.1	1297.7	NA	-	-	NA
8-12	-	1280.3	1297.9	NA	-	-	NA
8-15	trace	1277.9	1297.7	NA	-	-	NA
8-16	2.90	1281.4	1297.7	NA	-	-	NA
8-17	-	1282.6	1297.7	NA	-	-	NA
8-18	-	1281.4	1297.7	NA	-	-	NA
8-19	0.10	1280.6	1297.7	NA	-	-	NA
8-22	0.60	1278.1	1297.7	NA	-	-	NA
8-23	0.05	1280.8	1297.7	NA	-	-	NA
8-24	-	1278.1	1297.7	NA	-	-	NA
8-25	-	1278.8	1297.7	NA	-	-	NA
8-26	-	1278.4	1297.7	NA	-	-	NA

8-27	-	1279.1	1297.5	1302.2	1302.2	1302.2	1302.1
8-29	1.10	1278.1	1297.7	-	-	-	-
8-30	-	1277.4	1297.7	-	-	-	-
8-31	-	1277.4	1297.7	-	-	-	-
9-1	-	1277.8	1297.7	-	-	-	-
9-2	-	1278.8	1297.4	-	-	-	-
9-4	-	1277.1	1297.5	1302.2	1302.2	1302.1	1302.0
9-6	0.75	1277.1	1297.7	-	-	-	-
9-7	-	1278.1	1297.7	-	-	-	-
9-8	-	1277.4	1297.7	-	-	-	-
9-9	0.70	1277.1	1297.7	-	-	-	-
9-12	0.10	1277.1	1297.7	-	-	-	-
9-13	0.05	1277.1	1297.7	-	-	-	-
9-14	0.20	1277.1	1297.7	-	-	-	-
9-15	-	1277.3	1297.7	-	-	-	-
9-16	-	1277.4	1297.7	-	-	-	-
9-19	-	1276.9	1297.7	-	-	-	-
9-20	-	1277.3	1297.7	-	-	-	-
9-21	-	1277.1	1297.7	-	-	-	-
9-22	frost	1276.9	1297.7	-	-	-	-
9-23	frost	1276.9	1297.9	-	-	-	-
9-26	-	1276.8	1297.4	-	-	-	-
9-27	-	1277.8	1297.4	-	-	-	-
9-28	-	1277.4	1297.7	1302.0	1302.0	1301.9	1301.9

a.s.l. = feet above sea level

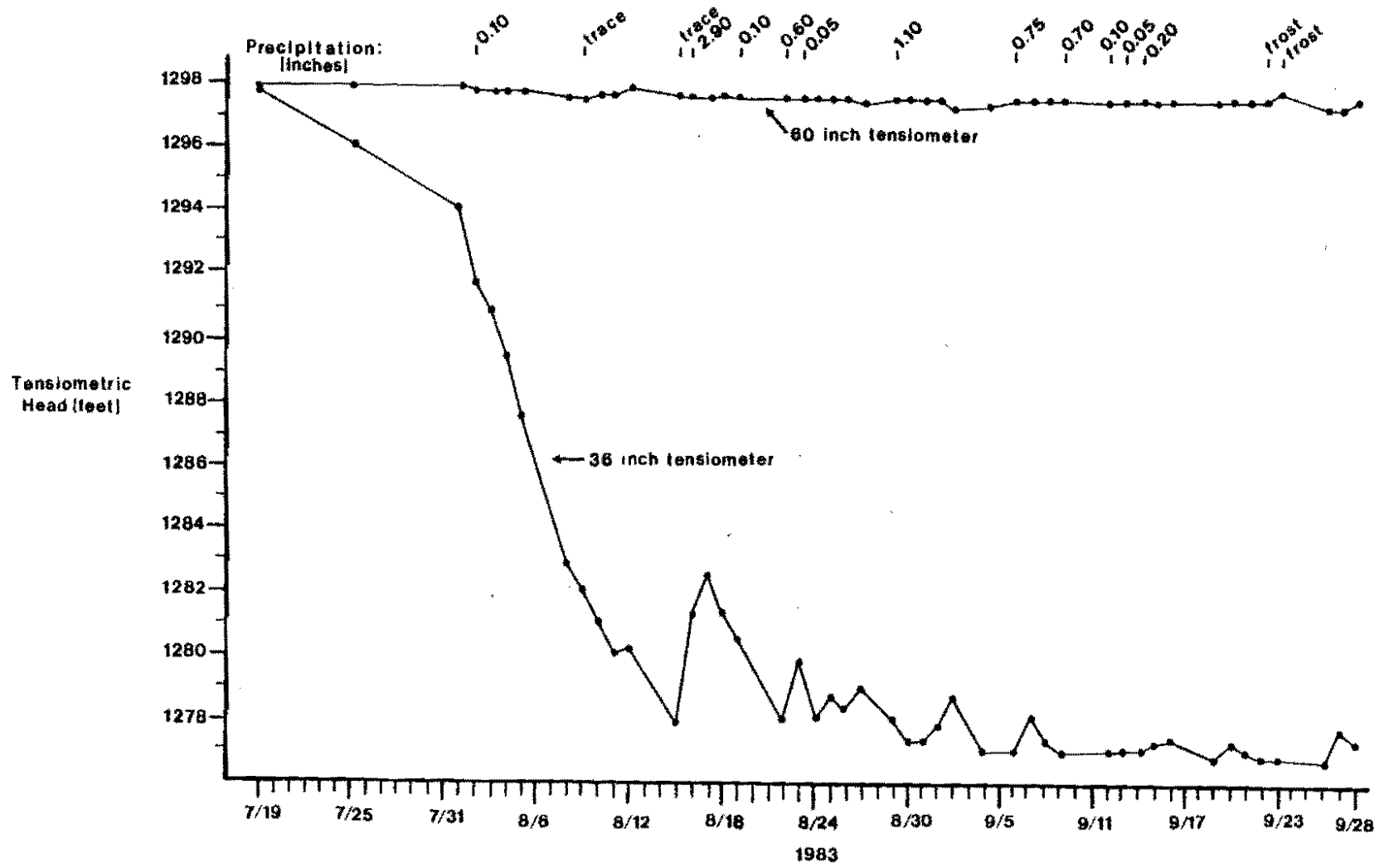
Table 3
PRECIPITATION, TENSIOMETRIC HEAD,
AND HYDRAULIC HEAD
AT
130-59-1CDD

Date 1984	Prec. inches	36 in. tens. a.s.l.	60 in. tens. a.s.l.	Water table well a.s.l.	20 ft. well a.s.l.	60 ft. well a.s.l.	80 ft. well a.s.l.
4-18	NA	NA	NA	1304.5	-	1304.5	1303.1
4-19	NA	NA	NA	1304.6	1304.4	1304.5	1303.1
4-20	NA	NA	NA	-	1304.4	-	-
4-21	NA	NA	NA	-	1304.4	-	-
4-22	NA	NA	NA	1304.8	1304.5	1304.7	1303.3
4-23	NA	NA	NA	1304.8	1304.6	-	1303.3
4-24	NA	NA	NA	-	-	-	-
4-25	-	1300.3	1298.5	-	-	1304.7	-
4-26	0.45	1301.0	1299.2	1305.1	1304.6	-	1303.5
4-27	3.00	1302.3	1299.5	1305.2	1305.0	1305.0	1303.6
4-28	-	-	-	-	-	1305.1	-
4-29	-	-	-	-	-	1305.1	-
4-30	0.10	1302.0	1299.7	1305.2	1305.0	1305.1	1303.7
5-1	-	1301.3	1299.5	1305.1	1304.9	1305.1	1303.6
5-2	-	1302.0	1299.9	1305.2	1304.9	1305.1	1303.6
5-3	0.05	1302.7	1300.7	1305.2	1305.0	1305.1	1303.7
5-4	0.75	1302.2	1300.0	1205.2	1305.1	1305.1	1303.8
5-5	-	-	-	-	1305.2	-	-
5-6	-	-	-	-	1305.2	-	-
5-7	1.00	1302.3	1300.0	1305.2	1305.0	1305.2	1303.9
5-8	-	1302.5	1300.2	1305.3	1305.1	1305.2	1303.8
5-9	frost	1302.5	1300.7	1305.4	1305.2	1305.2	1303.9

5-10	-	1301.8	1300.2	1305.4	1305.2	1305.3	1304.0
5-11	-	1302.2	1300.0	1305.2	1305.0	1305.2	1304.0
5-12	-	-	-	-	1305.1	1305.1	-
5-13	-	-	-	1304.9	1305.1	-	-
5-14	0.10	1301.2	1299.2	1305.1	1305.0	1305.1	1304.0
5-15	-	1301.8	1299.9	1305.1	1305.0	1305.1	1304.1
5-16	-	1301.7	1300.0	1305.3	1305.1	1305.2	1304.1
5-17	-	1301.2	1300.0	1305.2	1305.0	1305.3	1304.1
5-18	-	1301.5	1299.9	1305.1	1305.0	1305.2	1304.2
5-19	-	-	-	1305.2	1304.8	1305.1	1304.2
5-20	-	-	-	1305.1	-	1305.1	1304.3
5-21	0.75	1301.7	1299.7	1305.0	1304.8	1304.9	1304.3
5-22	0.10	1301.5	1299.5	1304.8	1304.7	1304.9	1304.2
5-23	-	1301.3	1299.2	1304.7	1304.5	1304.7	1304.2
5-24	-	1301.7	1299.5	1304.6	1304.4	1304.7	1304.3
5-25	trace	1301.7	1299.7	1304.5	1304.3	1304.6	1304.2
5-26	-	-	-	1304.4	1304.2	1304.5	1304.2
5-27	-	-	-	1304.3	1304.1	-	1304.2
5-28	-	-	-	1304.2	1304.0	-	1304.2
5-29	-	1301.0	1298.7	1304.2	1304.0	1304.3	1304.2
5-30	-	1301.0	1298.9	1304.2	1304.0	1304.2	1304.2
5-31	-	1301.3	1299.4	1304.2	1303.9	1304.2	1304.2
6-1	-	1301.3	1299.4	1304.0	1303.9	1304.1	1304.1
6-2	-	-	-	1303.9	1303.8	1304.0	-
6-3	-	-	-	1303.9	1303.8	1304.0	-
6-4	0.54	1300.7	1298.9	1303.9	1303.8	1303.9	1304.3

a.s.l. = feet above sea level

Figure 12. Tensiometric head and precipitation data from July 19, 1983 to September 28, 1983 at 130-59-1CCC.


Precipitation: (inches)
0.10
trace
trace
2.90
0.10
0.60
0.05
1.10
0.75
0.70
0.10
0.05
0.20
frost
frost
60 inch tensiometer
36 inch tensiometer
Tensiometric Head (feet)
1298
1296
1294
1292
1290
1288
1286
1284
1282
1280
1278
7/19
7/25
7/31
8/6
8/12
8/18
8/24
8/30
9/5
9/11
9/17
9/23
9/28
1983

The tensiometers were again installed on April 25, 1984 and operated until June 4, 1984 at 130-59-1CDD (Figure 13). Consistently throughout the period, immediately after a rainfall, the 36-inch tensiometer measured an increase in hydraulic head. The 60-inch tensiometer had a corresponding increase but did not respond as quickly to the precipitation event as did the 36-inch tensiometer. Downward gradients persisted throughout the period.

Water Table

Water table maps (Figures 14-25) were prepared for each water-level measurement period. The water elevations (in feet) are abbreviated, with the last four digits written next to the well locations.

Initial water-table data supplied by the USBR indicates that movement of groundwater is from east to west across the lake plain toward the James River. Water levels from observation wells installed in and around the topographic depression reveal a weak lateral component of flow toward the center of the depression and a component of flow along the axis of the depression toward the James River (Figure 14). A groundwater mound is present at 131-59-33DDD where water apparently flows away from the center of the trough. The water-table map for July 19, 1983 indicates outward flow from the center of the depression (130-59-12) (Figure 15). This reversal of flow is the result of a major recharge event prior to July 19.

After July 19, 1983, water levels declined rapidly in the middle of the depression (130-59-12) until August 27, 1983, after which the rate of decline decreased. The decline continued to mid-February (Figures

Figure 13. Tensiometric head and precipitation data from April 25, 1984 to June 4, 1984 at 130-59-1CDD.

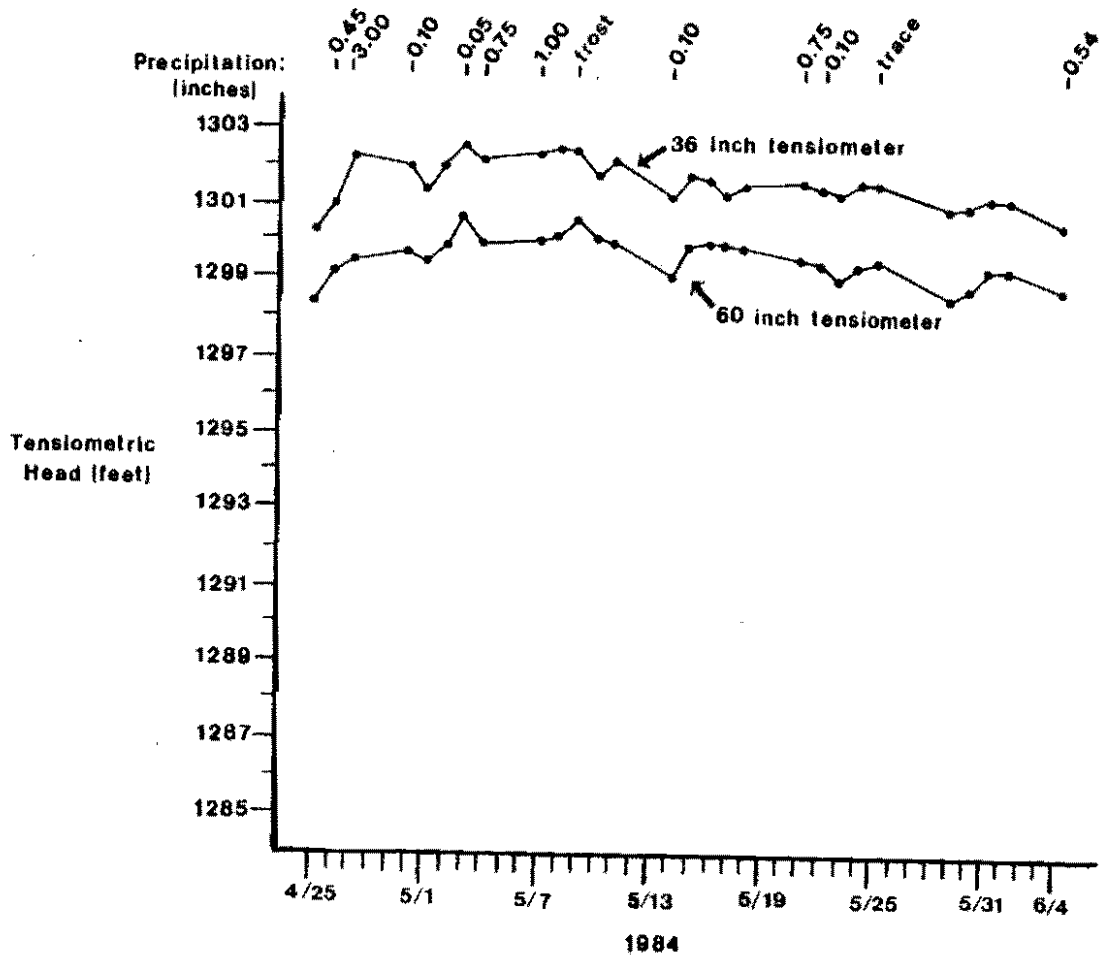

Precipitation: (inches)
0.45
3.00
0.10
0.05
0.75
1.00
frost
0.10
0.75
0.10
trace
0.54
1303
1301
1299
1297
1295
1293
1291
1289
1287
1285
Tensiometric Head (feet)
36 inch tensiometer
60 inch tensiometer
4/25
5/1
5/7
5/13
5/19
5/25
5/31
6/4
1984

Figure 14. Water table map for May 30, 1983.

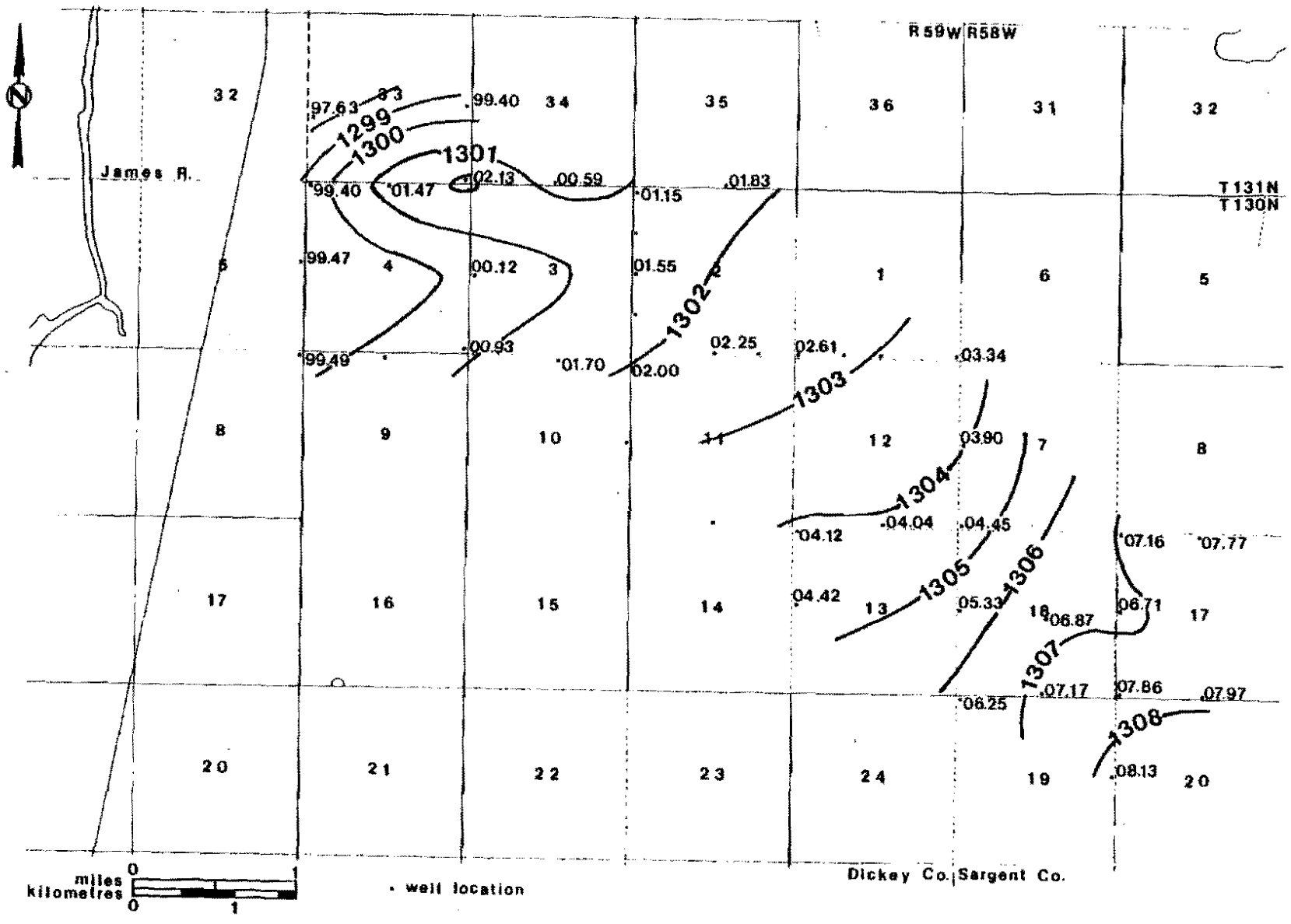

R59W R58W
T131N
T130N
James R.
1299
1300
1301
1302
1303
1304
1305
1306
1307
1308
97.63
99.40
99.40
01.47
02.13
00.59
01.15
01.83
99.47
00.12
01.55
99.49
00.93
01.70
02.00
02.25
02.61
03.34
03.90
04.12
04.04
04.45
04.42
05.33
06.87
06.71
07.16
07.77
06.25
07.17
07.86
07.97
08.13
32
33
34
35
36
31
32
5
4
3
2
1
6
5
8
9
10
11
12
7
8
17
16
15
14
13
18
17
20
21
22
23
24
19
20
0 1
miles
kilometres
0 1
· well location
Dickey Co.
Sargent Co.

Figure 15. Water table map for July 19, 1983.

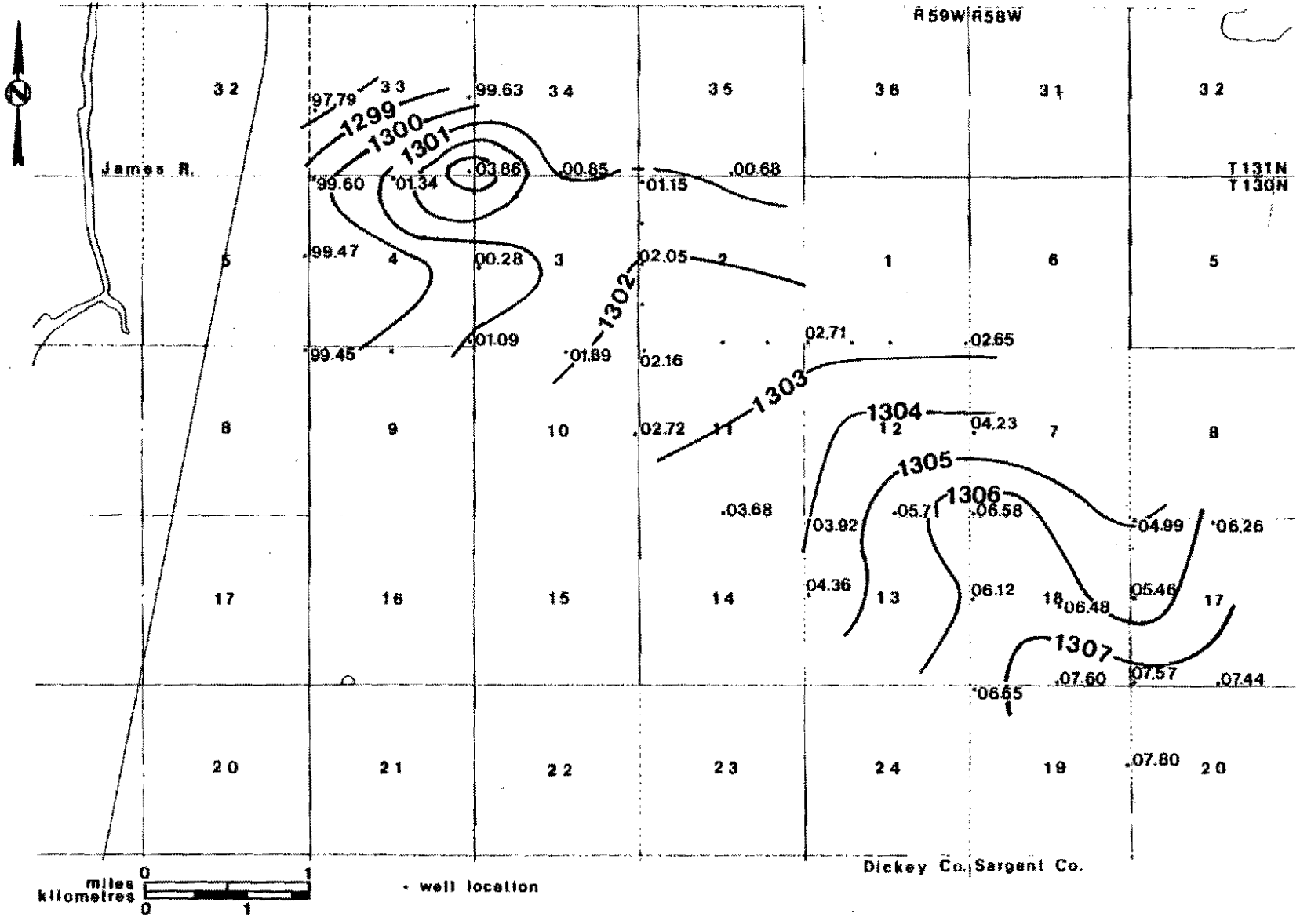

R59W R58W
James R.
T131N
T130N
1299
1300
1301
1302
1303
1304
1305
1306
1307
97.79
99.63
99.60
01.34
03.86
00.85
01.15
00.68
99.47
00.28
02.05
99.45
01.09
01.89
02.16
02.71
02.65
02.72
04.23
03.68
03.92
05.71
06.58
04.99
06.26
04.36
06.12
06.48
05.46
06.65
07.60
07.57
07.44
07.80
32
33
34
35
36
31
32
5
4
3
2
1
6
5
8
9
10
11
12
7
8
17
16
15
14
13
18
17
20
21
22
23
24
19
20
miles
kilometres
0
1
0
1
well location
Dickey Co.
Sargent Co.

Figure 16. Water table map for August 27, 1983.

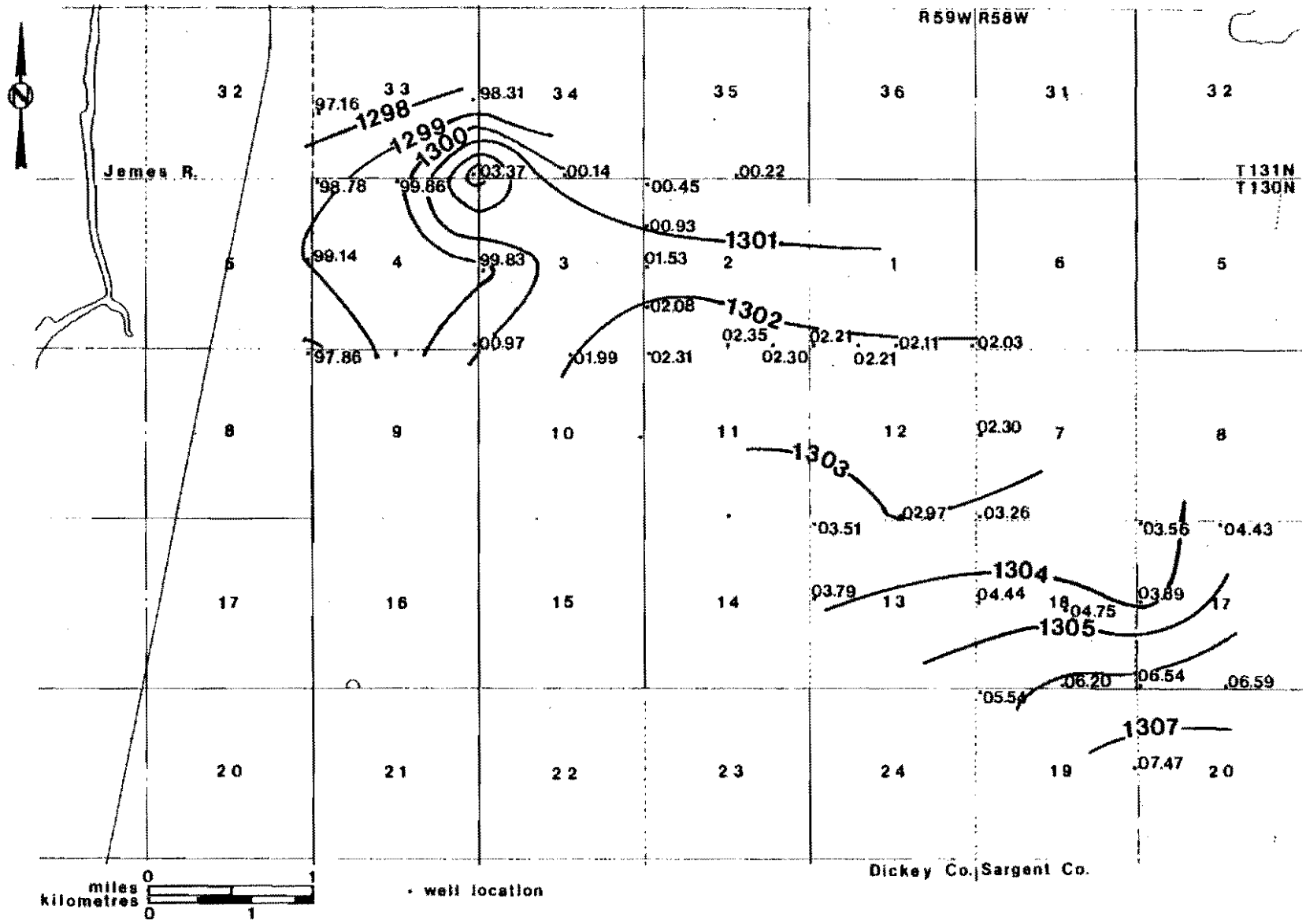

R59W R58W
T131N
T130N
James R.
1298
1299
1300
1301
1302
1303
1304
1305
1307
97.16
98.31
98.78
99.86
03.37
00.14
00.45
00.22
00.93
99.14
99.83
01.53
97.86
00.97
01.99
02.08
02.31
02.35
02.30
02.21
02.21
02.11
02.03
02.30
02.97
03.26
03.51
03.56
04.43
03.79
04.44
04.75
03.89
05.54
06.20
06.54
06.59
07.47
32
33
34
35
36
31
32
5
4
3
2
1
6
5
8
9
10
11
12
7
8
17
16
15
14
13
18
17
20
21
22
23
24
19
20
0
1
miles
kilometres
0
1
• well location
Dickey Co.
Sargent Co.

Figure 17. Water table map for September 28, 1983.

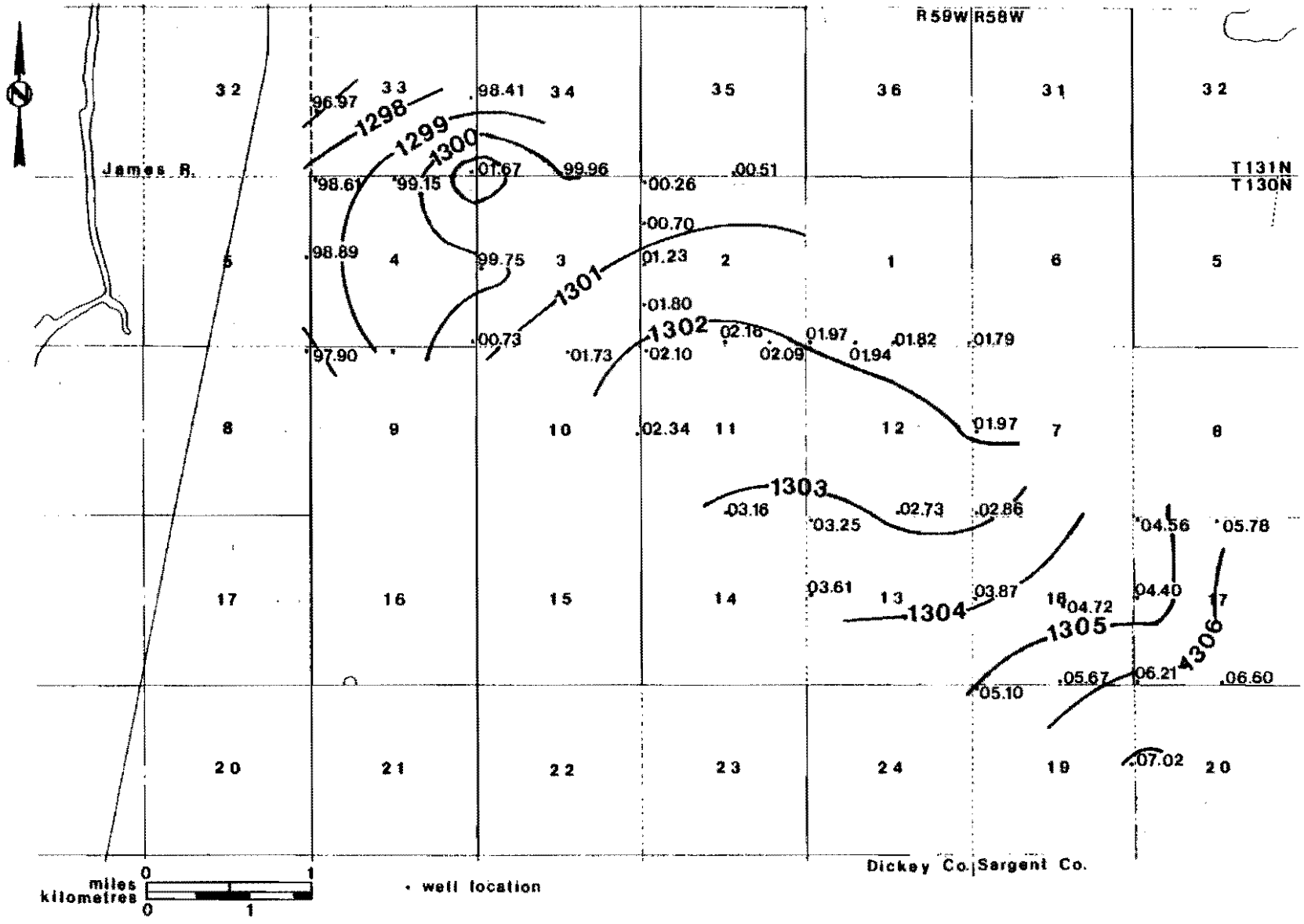

R59W R58W
T131N
T130N
James R.
32
33
34
35
36
31
32
5
4
3
2
1
6
5
8
9
10
11
12
7
8
17
16
15
14
13
18
17
20
21
22
23
24
19
20
1298
1299
1300
1301
1302
1303
1304
1305
1306
96.97
98.41
98.61
99.15
01.67
99.96
00.26
00.51
00.70
98.89
99.75
01.23
01.80
97.90
00.73
01.73
02.10
02.16
01.97
01.94
01.82
01.79
02.34
01.97
03.16
03.25
02.73
02.86
04.56
05.78
03.61
03.87
04.72
04.40
05.10
05.67
06.21
06.60
07.02
miles
kilometres
0
1
0
1
well location
Dickey Co.
Sargent Co.

Figure 18. Water table map for October 28, 1983.

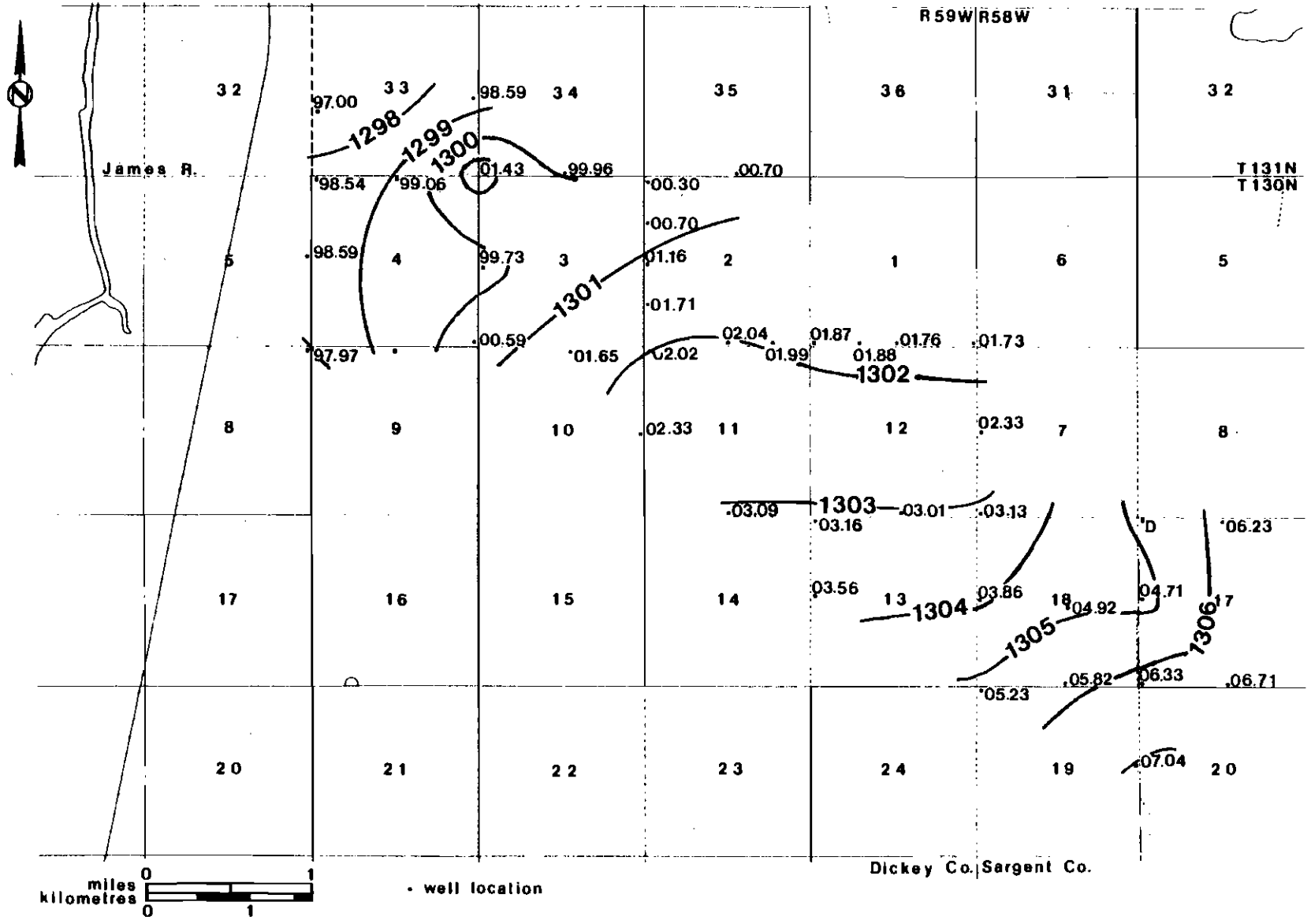

R59W R58W
James R.
T131N
T130N
1298
1299
1300
1301
1302
1303
1304
1305
1306
97.00
98.59
99.96
00.70
98.54
99.06
01.43
00.30
00.70
98.59
99.73
01.16
01.71
97.97
00.59
01.65
02.02
02.04
01.99
01.87
01.88
01.76
01.73
02.33
02.33
03.09
03.16
03.01
03.13
06.23
03.56
03.86
04.92
04.71
05.23
05.82
06.33
06.71
07.04
32 33 34 35 36 31 32
5 4 3 2 1 6 5
8 9 10 11 12 7 8
17 16 15 14 13 18 17
20 21 22 23 24 19 20
miles
kilometres
0 1
0 1
• well location
Dickey Co. Sargent Co.

Figure 19. Water table map for November 25, 1983.

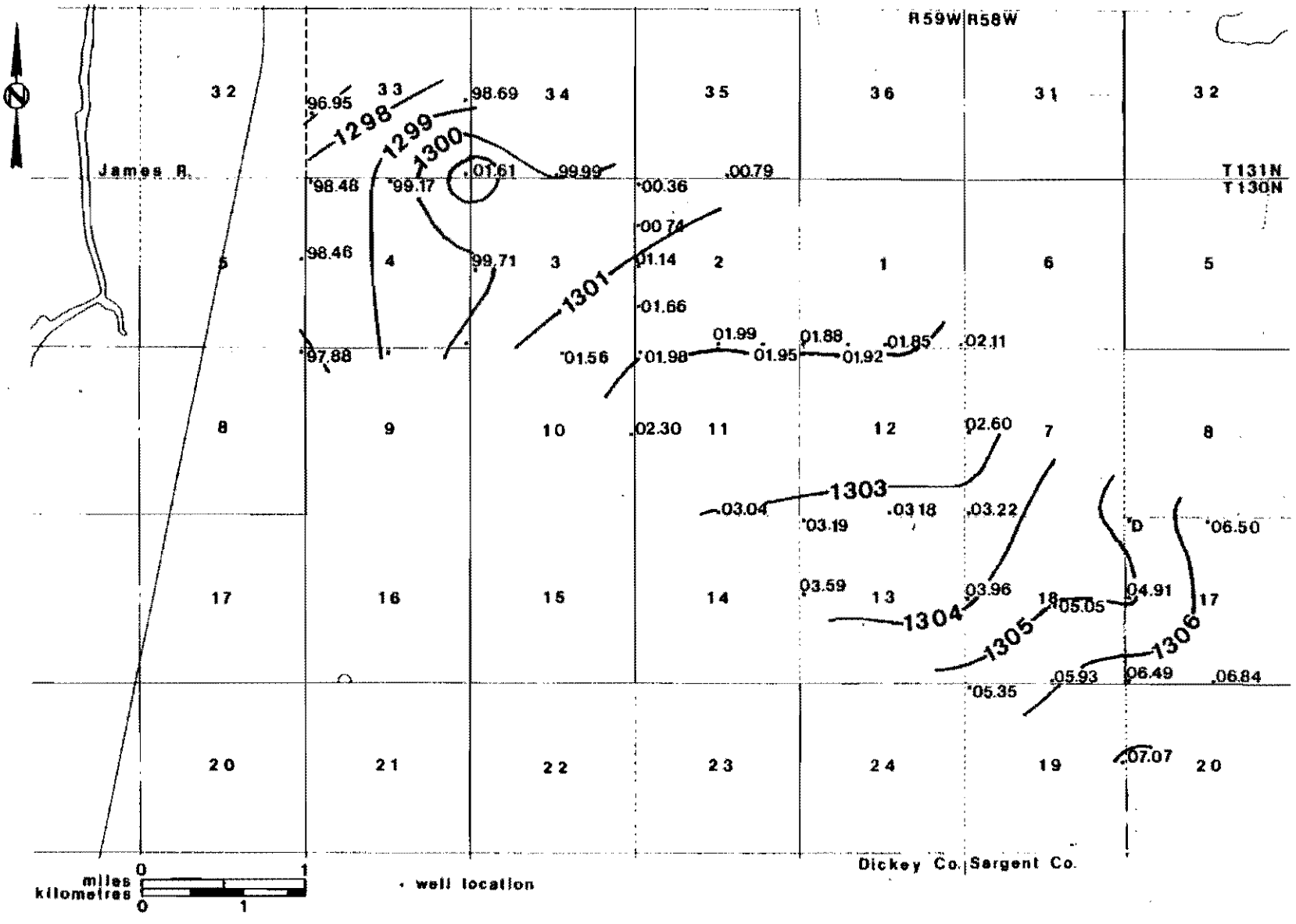

R59W R58W
T131N
T130N
James R.
32
33
34
35
36
31
32
5
4
3
2
1
6
5
8
9
10
11
12
7
8
17
16
15
14
13
18
17
20
21
22
23
24
19
20
96.95
98.69
1298
1299
1300
.01.61
.99.99
.00.79
98.48
99.17
.00.36
.00.74
98.46
99.71
1301
01.14
.01.66
97.88
01.56
01.98
01.99
01.95
01.88
01.92
01.85
02.11
02.30
02.60
1303
03.04
03.19
03.18
03.22
D
06.50
03.59
03.96
04.91
1304
05.05
1305
1306
05.93
06.49
06.84
05.35
07.07
miles
kilometres
0
1
0
1
well location
Dickey Co.
Sargent Co.

Figure 20. Water table map for January 6, 1984.

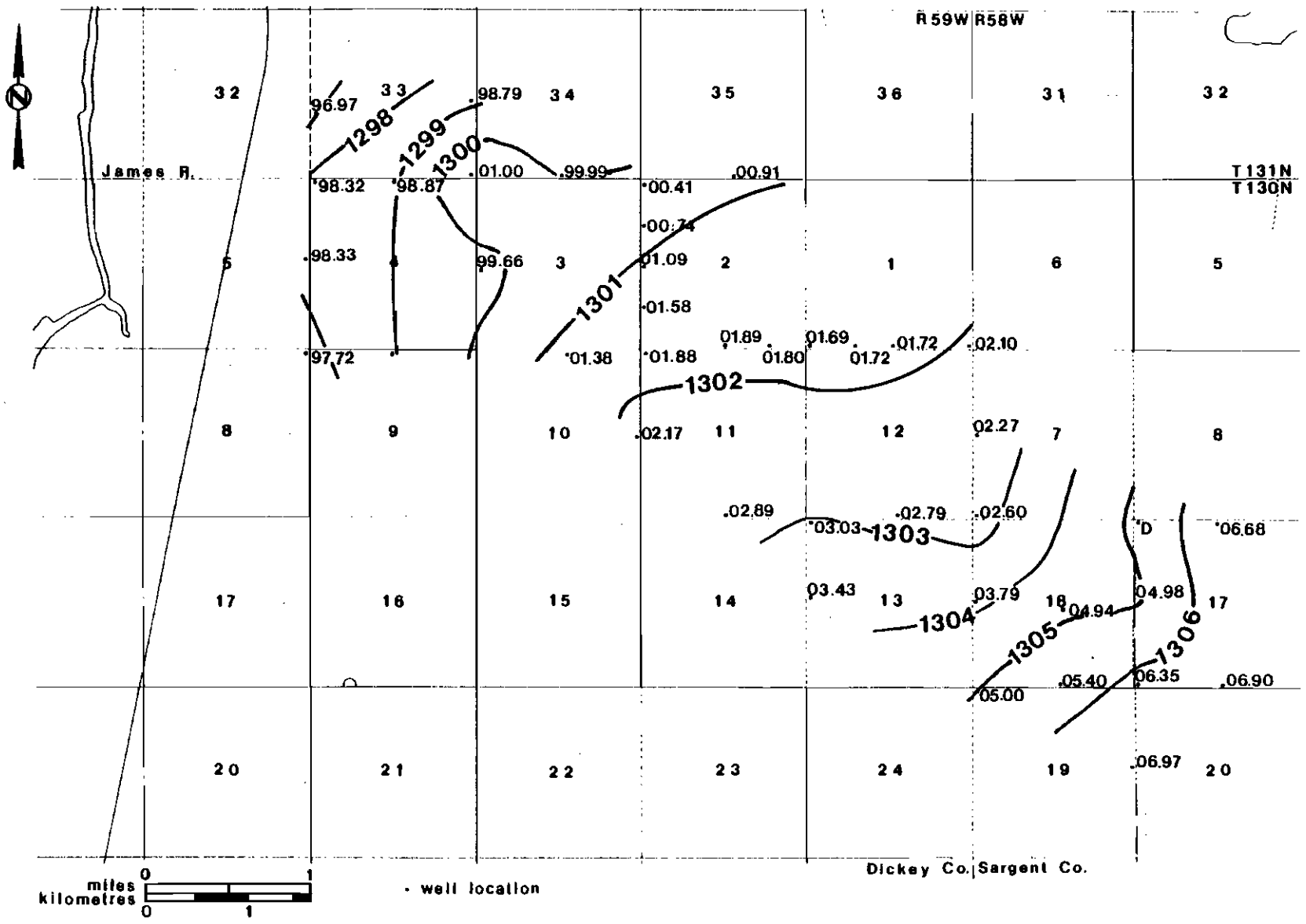

R59W R58W
T131N
T130N
James R.
32
33
34
35
36
31
32
5
4
3
2
1
6
5
8
9
10
11
12
7
8
17
16
15
14
13
18
17
20
21
22
23
24
19
20
96.97
98.79
98.32
98.87
01.00
99.99
00.91
00.41
00.74
98.33
99.66
01.09
01.58
97.72
01.38
01.88
01.89
01.80
01.69
01.72
01.72
02.10
02.17
02.27
02.89
02.79
02.60
03.03
03.43
03.79
04.94
04.98
05.00
05.40
06.35
06.90
06.97
06.68
D
1298
1299
1300
1301
1302
1303
1304
1305
1306
miles
kilometres
0
1
0
1
· well location
Dickey Co.
Sargent Co.

Figure 21. Water table map for February 2, 1984.

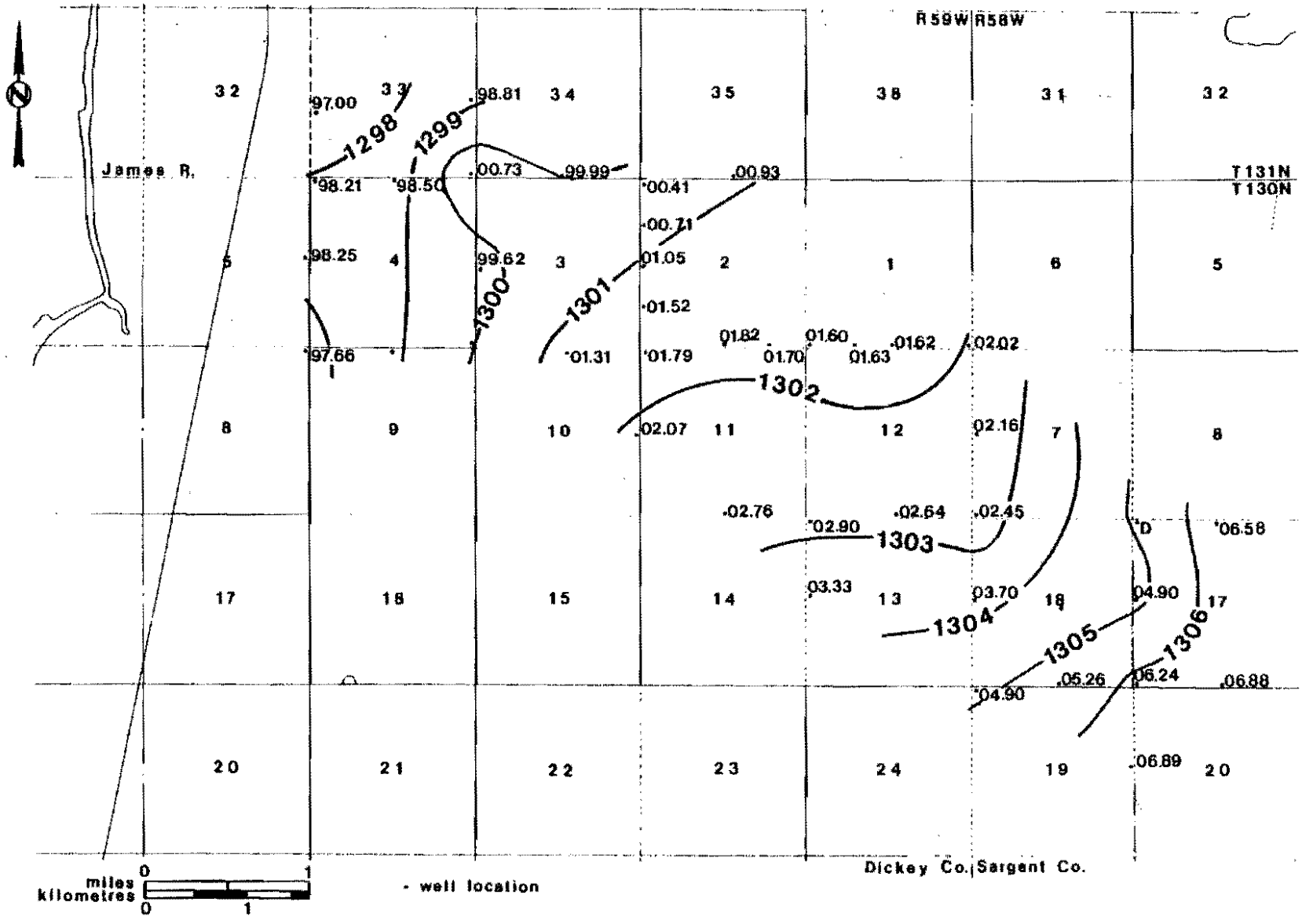
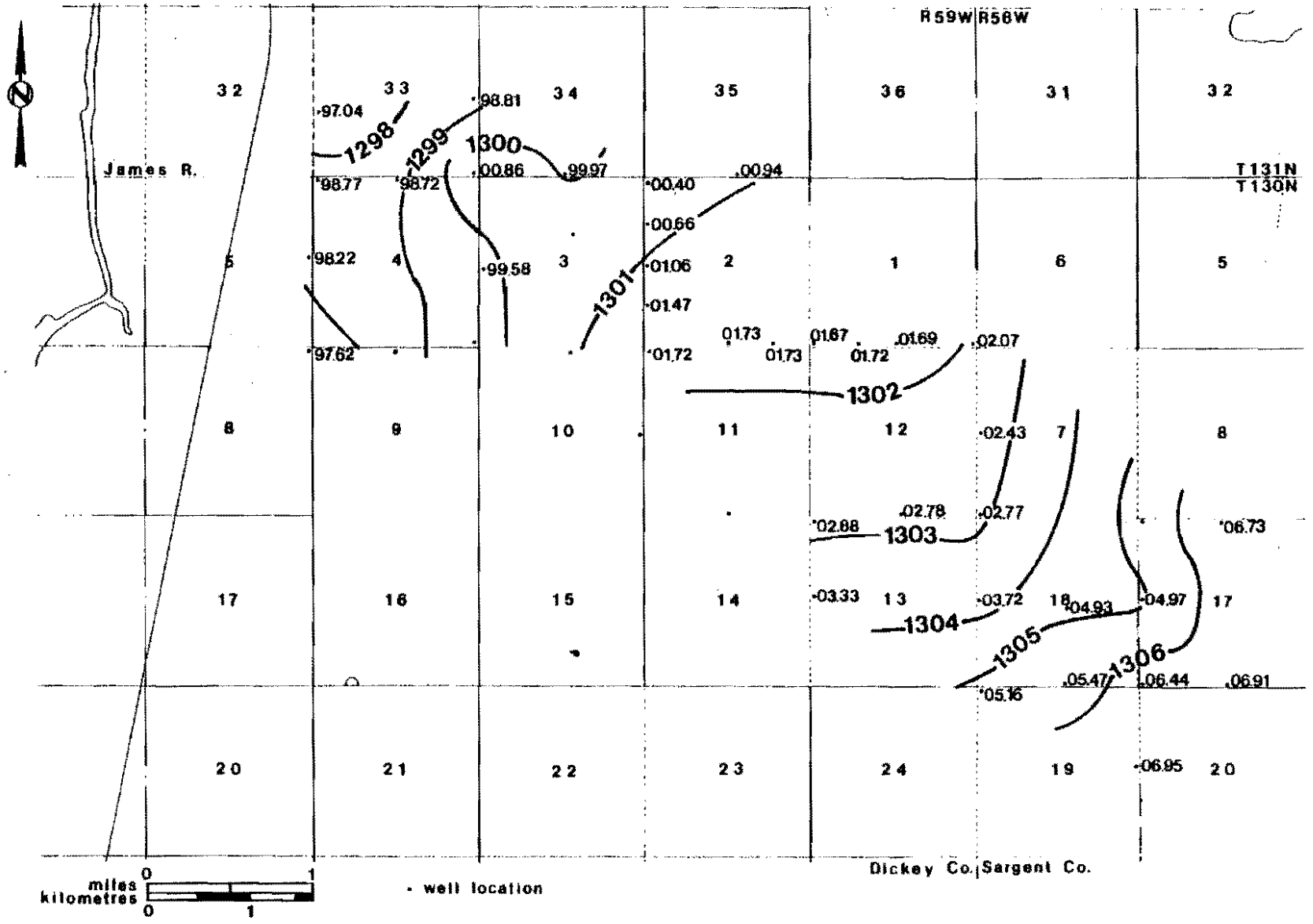

R59W R58W
T131N
T130N
James R.
32
33
34
35
36
31
32
5
4
3
2
1
6
5
8
9
10
11
12
7
8
17
18
15
14
13
18
17
20
21
22
23
24
19
20
97.00
98.81
98.21
98.50
00.73
99.99
00.41
00.93
00.71
98.25
99.62
01.05
01.52
97.66
01.31
01.79
01.82
01.60
01.70
01.63
01.62
02.02
02.07
02.16
02.76
02.90
02.64
02.45
03.33
03.70
04.90
06.58
05.26
06.24
06.88
04.90
06.89
1298
1299
1300
1301
1302
1303
1304
1305
1306
miles
kilometres
0
1
0
1
- well location
Dickey Co.
Sargent Co.

Figure 22. Water table map for February 18-26, 1984.


R59W R58W
T131N
T130N
James R.
32
33
34
35
36
31
32
5
4
3
2
1
6
5
8
9
10
11
12
7
8
17
16
15
14
13
18
17
20
21
22
23
24
19
20
97.04
98.81
98.77
98.72
00.86
99.97
00.40
00.94
00.66
98.22
99.58
01.06
01.47
97.62
01.72
01.73
01.67
01.72
01.69
02.07
02.43
02.78
02.77
02.88
06.73
03.33
03.72
04.93
04.97
05.16
05.47
06.44
06.91
06.95
1298
1299
1300
1301
1302
1303
1304
1305
1306
miles
kilometres
0
1
0
1
- well location
Dickey Co.
Sargent Co.

16-22). Note the general decay of the groundwater mound at 131-59-33DDD from July 19,1983 through February 18-26, 1984 (Figures 15-22).

Spring recharge began in March 1984, concurrent with the development of ponded water on the ground surface. The ponded water prevented water levels from being measured until April 19-26, at which time water samples were collected. The April 19-26, 1984 water-table map indicates a groundwater mound in the center of the depression with a large gradient in the eastern half of 130-59-2 and 130-59-11 (Figure 23). Outward flow from the center of the depression is indicated by lower hydraulic heads to the west, north, and east. A steep gradient is associated with the groundwater mound at 131-59-33DDD.

The water-table map for May 15, 1984 (Figure 24) indicates high water levels in the depression with flow toward the west-northwest. The gradient in the depression was not as great as the previous month, as indicated by wider-spaced contour lines.

By June 4, 1984 (Figure 25) the water-table contours were farther apart but still exhibited outward flow from the center of the depression, as evidenced by the 1303-foot contour. At this time the groundwater mound at 131-59-33DDD had started to dissipate and an overall decline in the water table occurred.

The water table fluctuates throughout the year but was drawn, arbitrarily, on the traverse cross-sections (Figures 9 and 10) using the water level data from August 27, 1983. Note that the water table intersects the surficial clay, near the center of the depression along both traverses. As will be discussed later, groundwater contact with the surficial clay is an important aspect of the physical and chemical processes operating in the local hydrogeologic system.

Figure 23. Water table map for April 19-26, 1984.

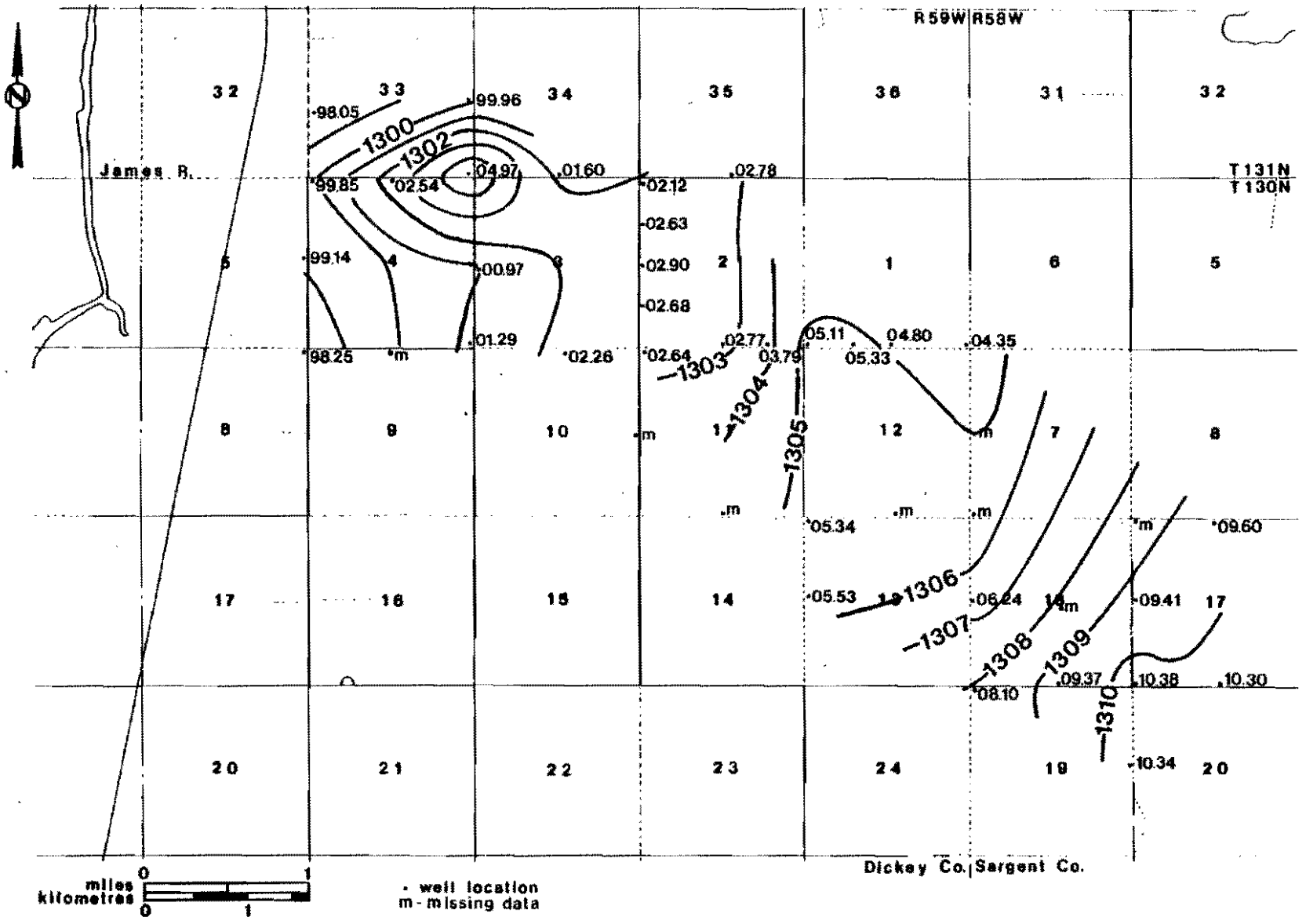

R59W R58W
T131N
T130N
James R.
32
33
34
35
36
31
32
5
4
3
2
1
6
5
8
9
10
11
12
7
8
17
16
15
14
13
18
17
20
21
22
23
24
19
20
98.05
99.96
99.85
02.54
04.97
01.60
02.12
02.78
02.63
99.14
00.97
02.90
02.68
98.25
01.29
02.26
02.64
02.77
03.79
05.11
04.80
04.35
05.33
05.34
05.53
06.24
09.41
09.60
08.10
09.37
10.38
10.30
10.34
1300
1302
1303
1304
1305
1306
1307
1308
1309
1310
Dickey Co.
Sargent Co.
miles
kilometres
0
1
0
1
- well location
m - missing data

Figure 24. Water table map for May 15, 1984.

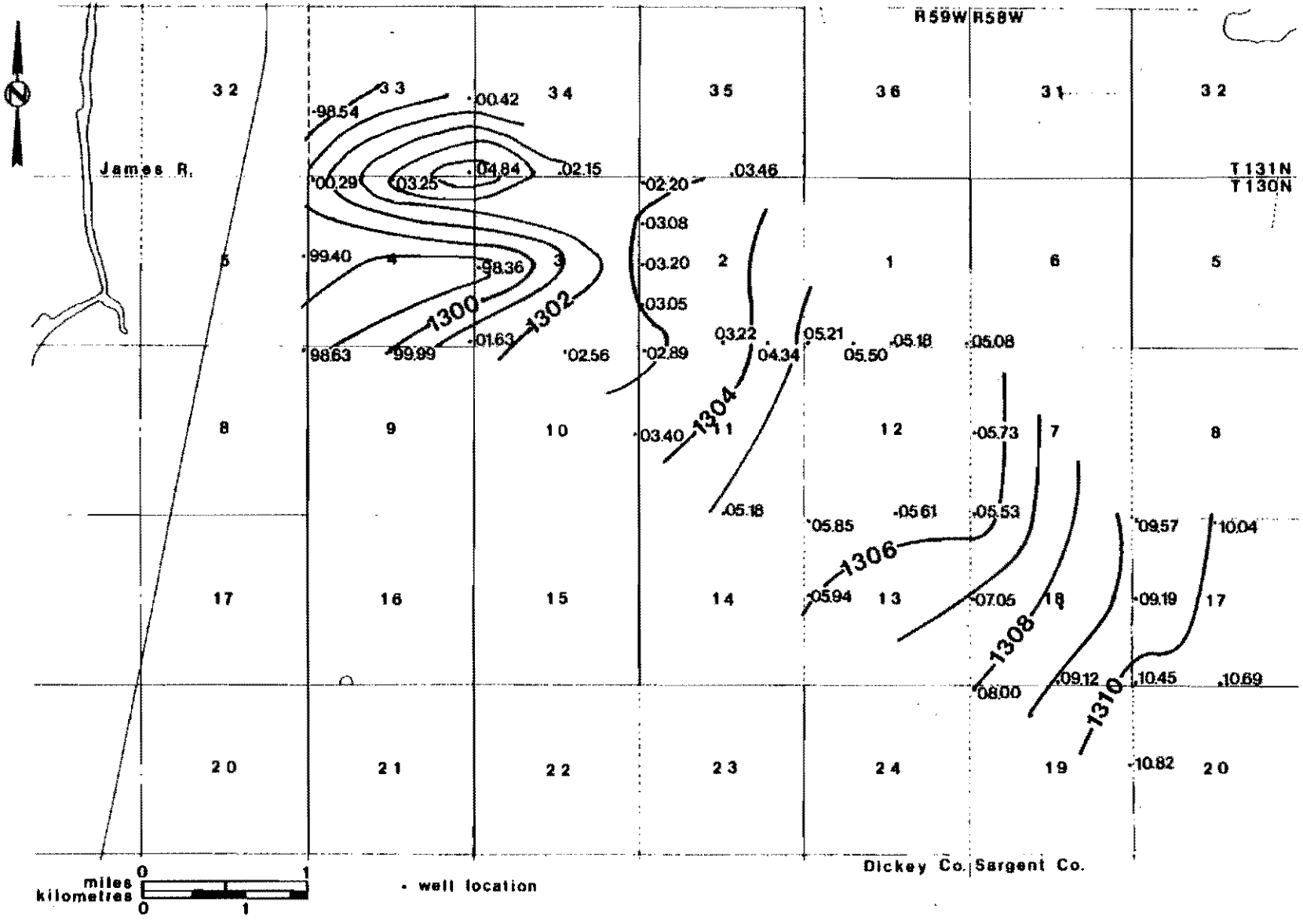
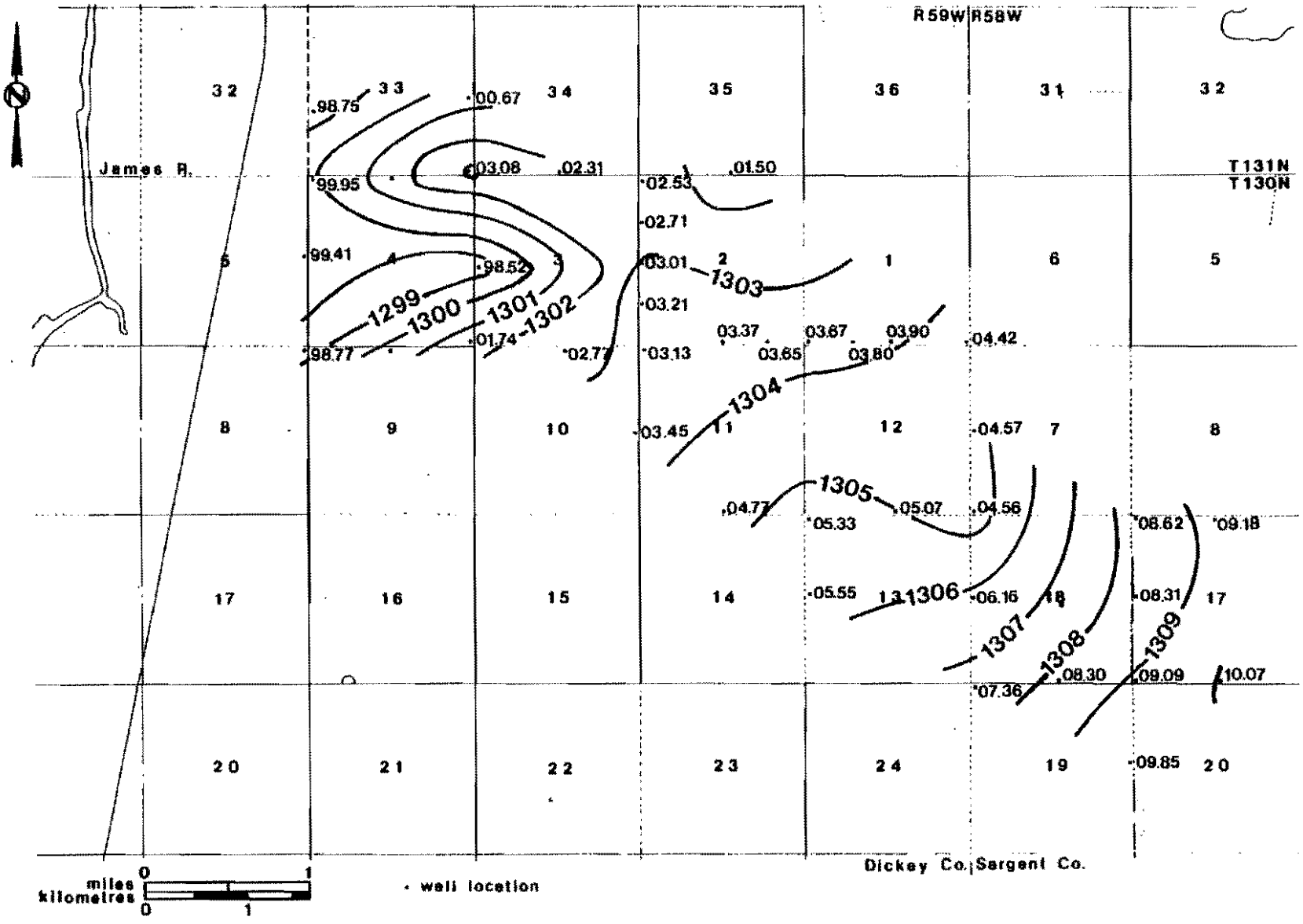

R59W R58W
T131N
T130N
James R.
32
33
34
35
36
31
32
5
4
3
2
1
6
5
8
9
10
11
12
7
8
17
16
15
14
13
18
17
20
21
22
23
24
19
20
-98.54
-00.42
-00.29
-03.25
-04.84
-02.15
-02.20
-03.46
-03.08
-99.40
-98.36
-03.20
-03.05
1300
1302
1304
1306
1308
1310
-98.63
-99.99
-01.63
-02.56
-02.89
-03.22
-04.34
-05.21
-05.50
-05.18
-05.08
-03.40
-05.73
-05.18
-05.85
-05.61
-05.53
-09.57
-10.04
-05.94
-07.05
-09.19
-08.00
-09.12
-10.45
-10.69
-10.82
miles
kilometres
0
1
0
1
• well location
Dickey Co.
Sargent Co.

Figure 25. Water table map for June 4, 1984.


R59W R58W
T131N
T130N
James R.
32
33
34
35
36
31
32
5
4
3
2
1
6
5
8
9
10
11
12
7
8
17
16
15
14
13
18
17
20
21
22
23
24
19
20
98.75
00.67
03.08
02.31
01.50
99.95
02.53
02.71
99.41
98.52
03.01
03.21
98.77
01.74
02.77
03.13
03.37
03.67
03.90
04.42
03.65
03.80
03.45
04.57
04.77
05.07
04.56
05.33
08.62
09.18
05.55
06.16
08.31
07.36
08.30
09.09
10.07
09.85
1299
1300
1301
1302
1303
1304
1305
1306
1307
1308
1309
Dickey Co.
Sargent Co.
miles
kilometres
0
1
0
1
well location

Hydraulic Conductivity

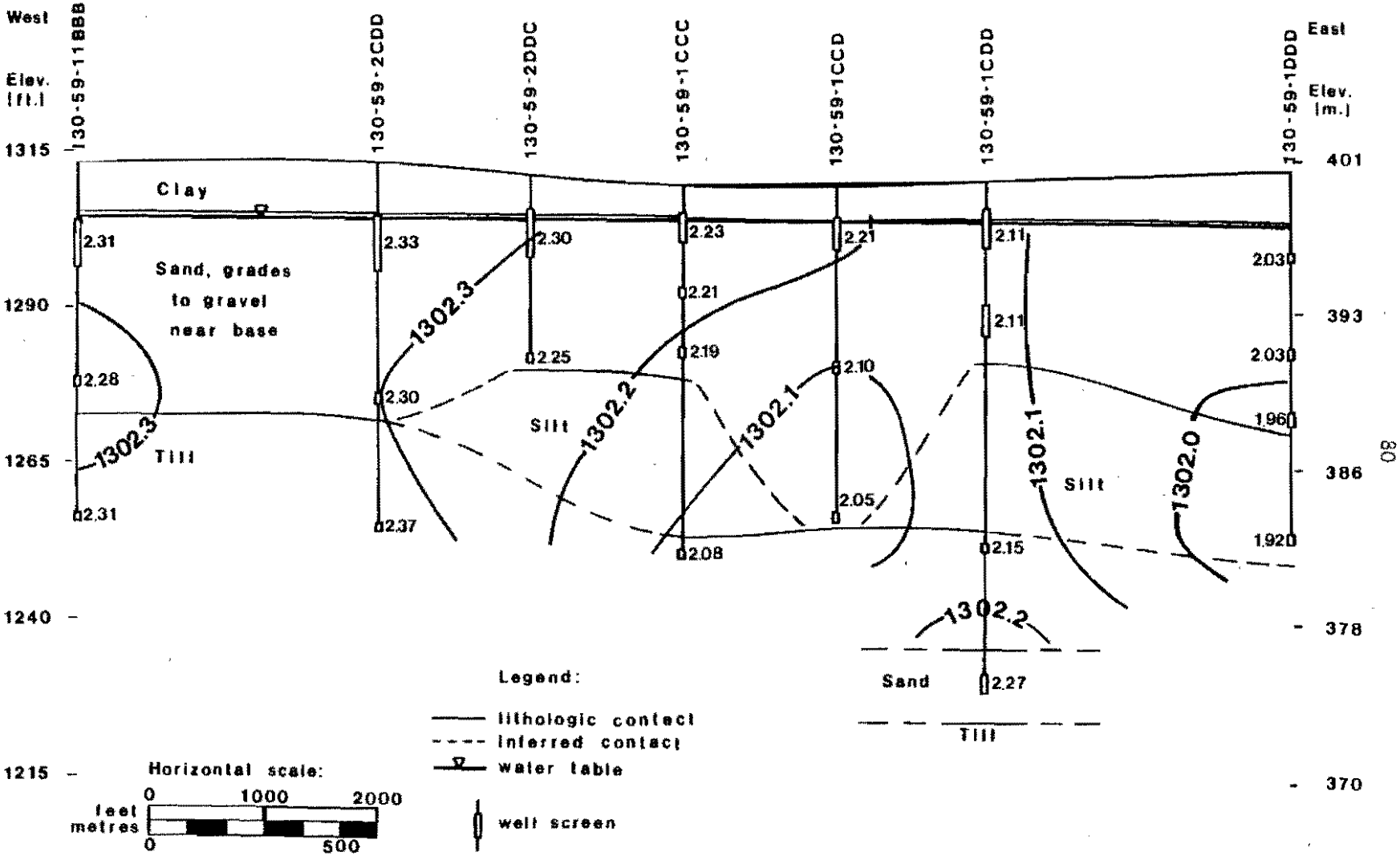
Hydraulic conductivity values for the different lithologies are listed in Appendix C. Most of the single-well response tests within the Oakes aquifer were characterized by recovery to equilibrium before enough data points could be collected. It is assumed that these wells are screened in materials having hydraulic conductivities greater than those listed.

The calculated hydraulic conductivity values for the till wells exhibit a range of nearly two orders of magnitude. Ranges of five orders of magnitude have been measured in North Dakota tills (Gerald Groenewold, verbal communication, 1984). One till well, NDSWC-12294 (130-59-2CDD), has a calculated hydraulic conductivity of $7.8X10^{-4}$ cm/s, a value which falls within the lower range of silty sand (Freeze and Cherry, 1979, p.29). Two of the till wells (NDSWC-12294 and NDSWC-12297) yielded such high conductivity values that it is assumed that their screens must intersect fractures. The remaining calculated conductivities fall within the normal ranges for each lithologic type.

Groundwater Flow

The groundwater flow system beneath a broad, flat plain is expected to have gentle gradients and slow flow (Toth, 1963). Groundwater flow along the east-west traverse can be characterized as having gentle gradients. On August 27, 1983 the east-west traverse had slightly higher hydraulic heads in the western part, decreasing to the east (Figure 26). The horizontal gradient at the water table, from 130-59-2CDD to 130-59-1DDD, is 0.3 feet (0.09 m) over 1.5 miles (2.4 km)

Figure 26. East-west hydraulic heads for August 27, 1983.


West
East
Elev. (ft.)
Elev. (m.)
130-59-11BBB
130-59-2CDD
130-59-2DDC
130-59-1CCC
130-59-1CCD
130-59-1CDD
130-59-1DDD
1315
1290
1265
1240
1215
401
393
386
378
370
Clay
Sand, grades to gravel near base
Silt
Till
Sand
Till
2.31
2.33
2.30
2.23
2.21
2.11
2.030
2.28
2.25
2.19
2.10
2.11
2.030
2.30
1.960
2.31
2.37
2.05
2.08
2.15
1.920
2.27
1302.3
1302.2
1302.1
1302.0
Legend:
lithologic contact
inferred contact
water table
well screen
Horizontal scale:
feet
metres
0
1000
2000
500

or $3.8X10^{-5}$ (Figure 26). A groundwater sink is located at 130-59-1CCD near the base of the aquifer and is noted in all of the cross-sections through February, 1984 (Figures 26-32).

A slight difference in hydraulic head between the lower sand and gravel aquifer and the Oakes aquifer occurs at 130-59-1CDD. The upward gradient increased across the intervening till from August, 1983 through February, 1984 (Figures 26-32). It is during this same period that groundwater flow changed from an eastward flow to a lateral westward flow toward the sink (Figures 26-32). During the months of November, 1983 through February, 1984 (Figures 29-32) the lateral flow intensified to a maximum in February (Figure 31). The east-west gradient on February 2, 1984, from 130-59-1DDD to 130-59-1CCD along the base of the aquifer, is $1.24X10^{-4}$ and the vertical gradient from the lower aquifer to the sink, across the intervening till, is $2.4X10^{-2}$ (assuming equal head throughout the lower aquifer).

Major recharge events disrupt flow paterns (Meyboom, 1966; Lissey, 1971; and Winter, 1983). The pattern of groundwater flow was disrupted by the spring, 1984 recharge event. During March most of the winter and spring snows melted and are assumed to have contributed to recharge. On March 29, 1984 a lake was observed to abutt the east-west traverse and was centered approximately at 130-59-12BC. The lake covered the eastern 1/3 of 130-59-11 and the western 2/3 of 130-59-12. Hydraulic head values measured on March 29 showed steep gradients and indicate groundwater movement outward from 130-59-1CCD and downward into the lower aquifer (Figure 33). This may represent the beginning of the recharge event. As recharge continued, a groundwater mound formed in

Figure 27. East-west hydraulic heads for September 28, 1983.

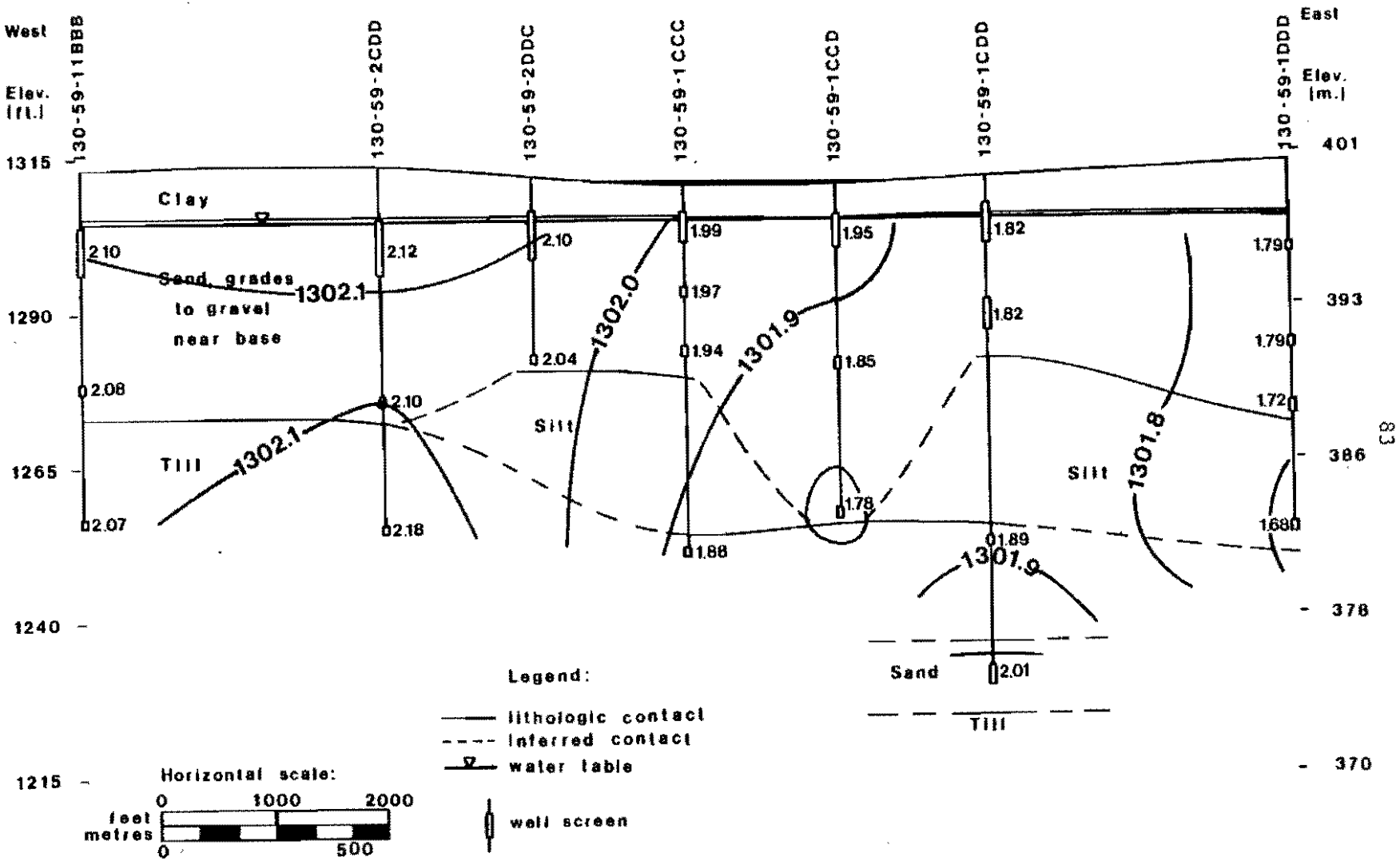

West
East
Elev. (ft.)
Elev. (m.)
130-59-11BBB
130-59-2CDD
130-59-2DDC
130-59-1CCC
130-59-1CCD
130-59-1CDD
130-59-1DDD
1315
1290
1265
1240
1215
401
393
386
378
370
Clay
Sand, grades to gravel near base
Silt
Till
Sand
2.10
2.12
2.10
1.99
1.95
1.82
1.790
1.97
1.82
1.790
2.08
2.04
1.94
1.85
1.72
2.10
2.07
2.18
1.88
1.78
1.89
1.680
2.01
1302.1
1302.1
1302.0
1301.9
1301.8
1301.9
Legend:
lithologic contact
inferred contact
water table
well screen
Horizontal scale:
0
1000
2000
feet
metres
0
500

Figure 28. East-west hydraulic heads for October 28, 1983.

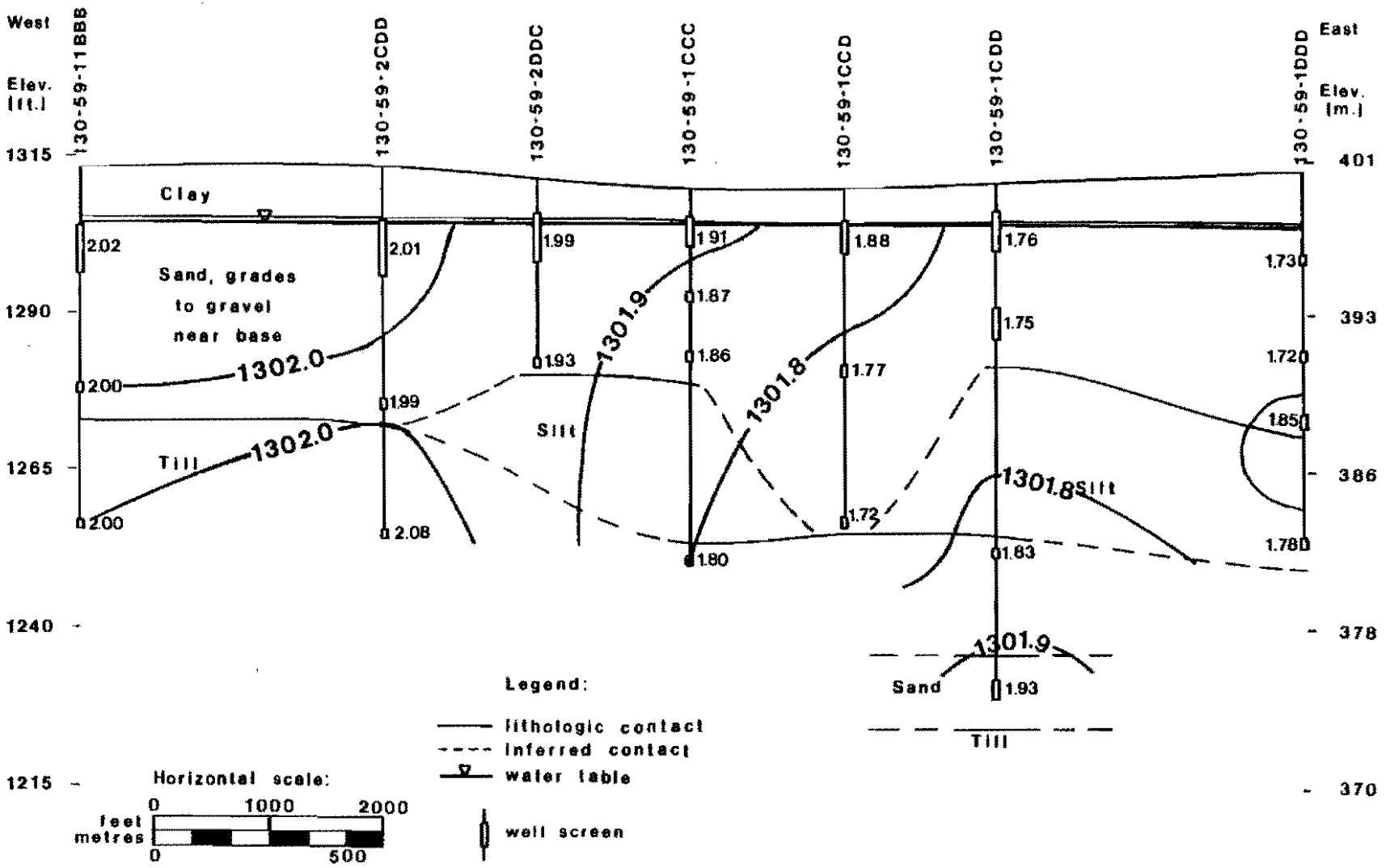

West
East
Elev. (ft.)
Elev. (m.)
1315
1290
1265
1240
1215
401
393
386
378
370
130-59-11BBB
130-59-2CDD
130-59-2DDC
130-59-1CCC
130-59-1CCD
130-59-1CDD
130-59-1DDD
Clay
Sand, grades to gravel near base
Silt
Till
Sand
2.02
2.01
1.99
1.91
1.88
1.76
1.730
1.87
1.75
1.93
1.86
1.77
1.720
2.00
1.99
1.850
2.00
2.08
1.73
1.80
1.83
1.780
1.93
1302.0
1301.9
1301.8
1301.8
1301.9
Legend:
lithologic contact
inferred contact
water table
well screen
Horizontal scale:
feet
metres
0
1000
2000
0
500

Figure 29. East-west hydraulic heads for November 25, 1983.

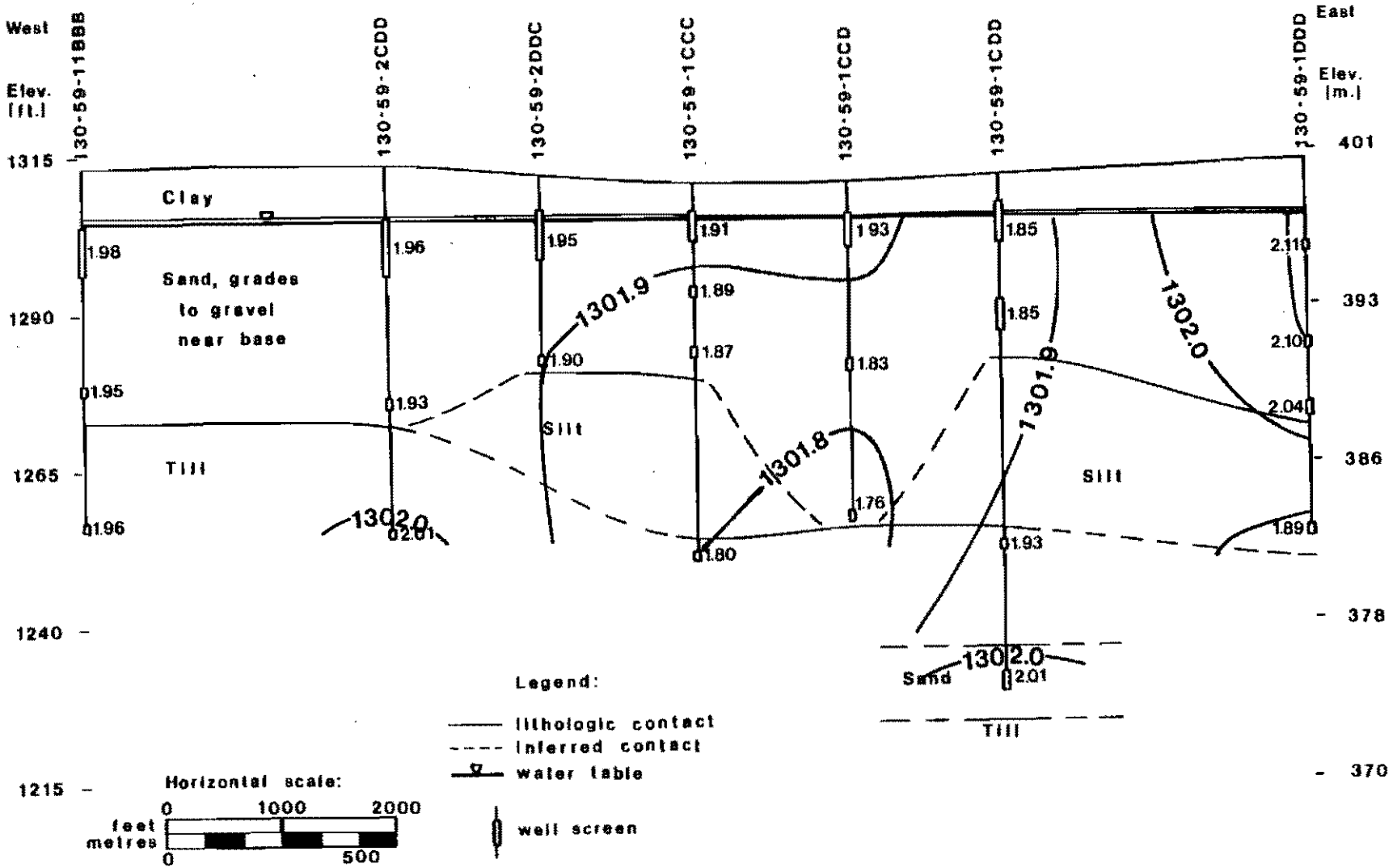

West
East
Elev. (ft.)
Elev. (m.)
130-59-11BBB
130-59-2CDD
130-59-2DDC
130-59-1CCC
130-59-1CCD
130-59-1CDD
130-59-1DDD
1315
1290
1265
1240
1215
401
393
386
378
370
Clay
Sand, grades to gravel near base
Till
Silt
Sand
1.98
1.96
1.95
1.91
1.93
1.85
2.110
1.89
1.85
2.100
1.90
1.87
1.83
2.04
1.95
1.93
1.76
1.890
1.96
2.01
1.80
1.93
1301.9
1302.0
1301.8
2.01
Legend:
lithologic contact
inferred contact
water table
well screen
Horizontal scale:
0
1000
2000
feet
metres
0
500

Figure 30. East-west hydraulic heads for January 6, 1984.

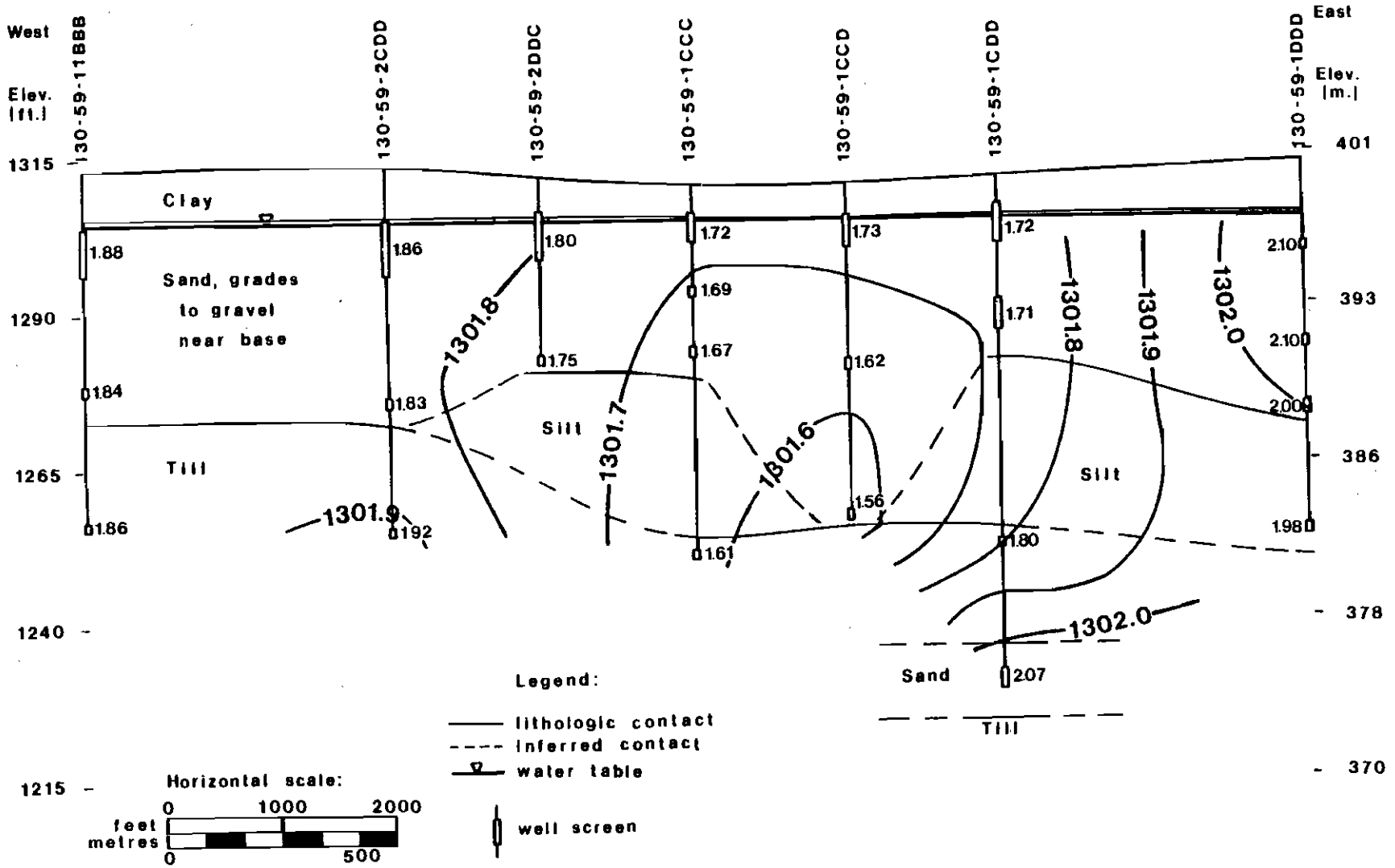

West
East
Elev. (ft.)
Elev. (m.)
130-59-11BBB
130-59-2CDD
130-59-2DDC
130-59-1CCC
130-59-1CCD
130-59-1CDD
130-59-1DDD
1315
1290
1265
1240
1215
401
393
386
378
370
Clay
Sand, grades to gravel near base
Silt
Till
Sand
1.88
1.86
1.80
1.72
1.73
1.72
2.10
1.69
1.71
2.10
1.84
1.75
1.67
1.62
2.00
1.83
1.86
1.92
1.61
1.56
1.80
1.98
2.07
1301.8
1301.7
1301.6
1301.9
1302.0
Legend:
lithologic contact
inferred contact
water table
well screen
Horizontal scale:
feet
metres
0
1000
2000
500

Figure 31. East-west hydraulic heads for February 2, 1984.

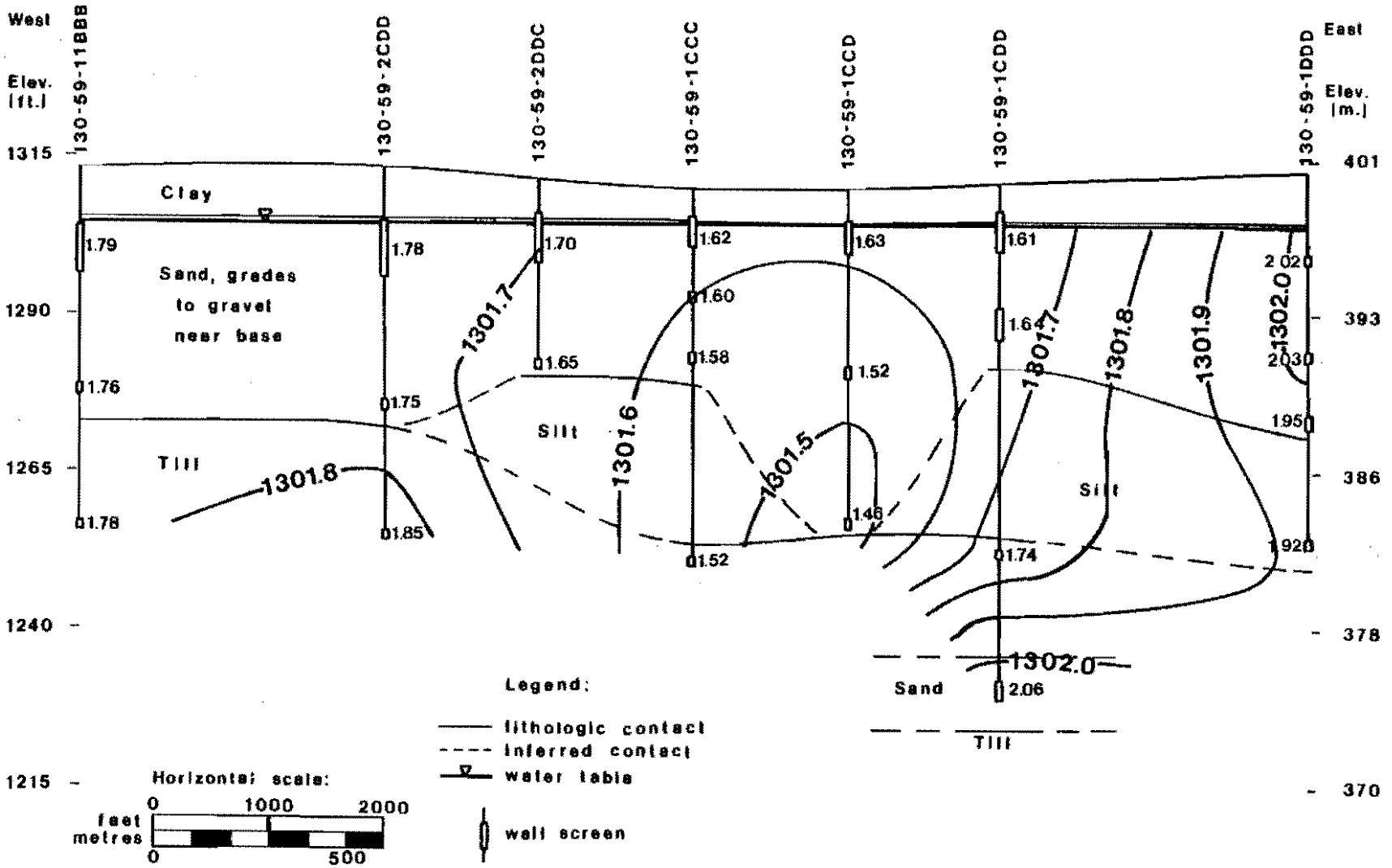

West
East
Elev. (ft.)
Elev. (m.)
130-59-11BBB
130-59-2CDD
130-59-2DDC
130-59-1CCC
130-59-1CCD
130-59-1CDD
130-59-1DDD
1315
1290
1265
1240
1215
401
393
386
378
370
Clay
Sand, grades to gravel near base
Till
Silt
Sand
1.79
1.78
1.70
1.62
1.63
1.61
2.020
1.60
1.64
1.65
1.58
1.52
2.030
1.76
1.75
1.95
1.78
1.85
1.52
1.46
1.74
1.92
2.06
1301.7
1301.6
1301.5
1301.8
1301.7
1301.8
1301.9
1302.0
1302.0
Legend:
lithologic contact
inferred contact
water table
wall screen
Horizontal scale:
feet
metres
0
1000
2000
500

Figure 32. East-west hydraulic heads for February 18-26, 1984.

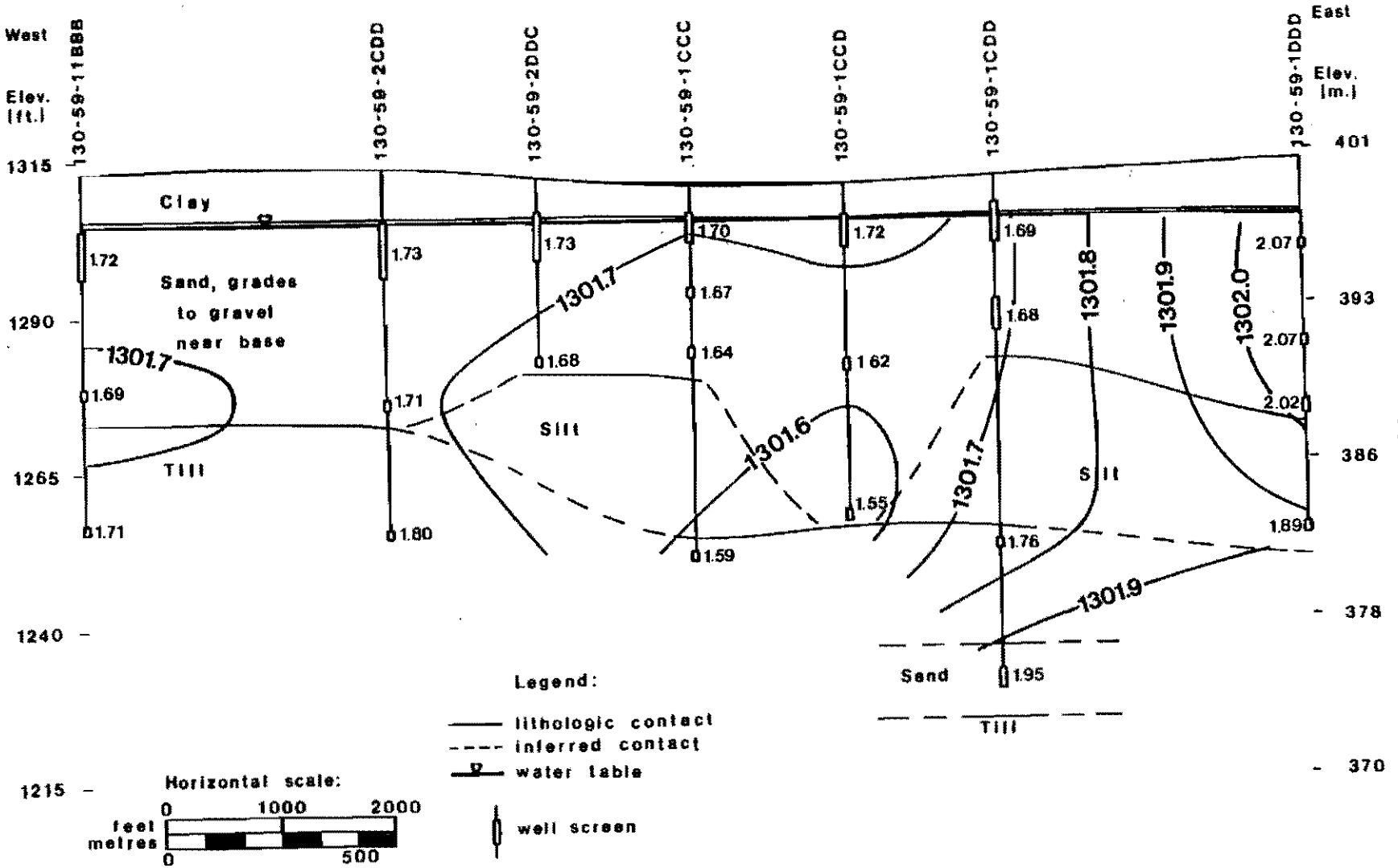
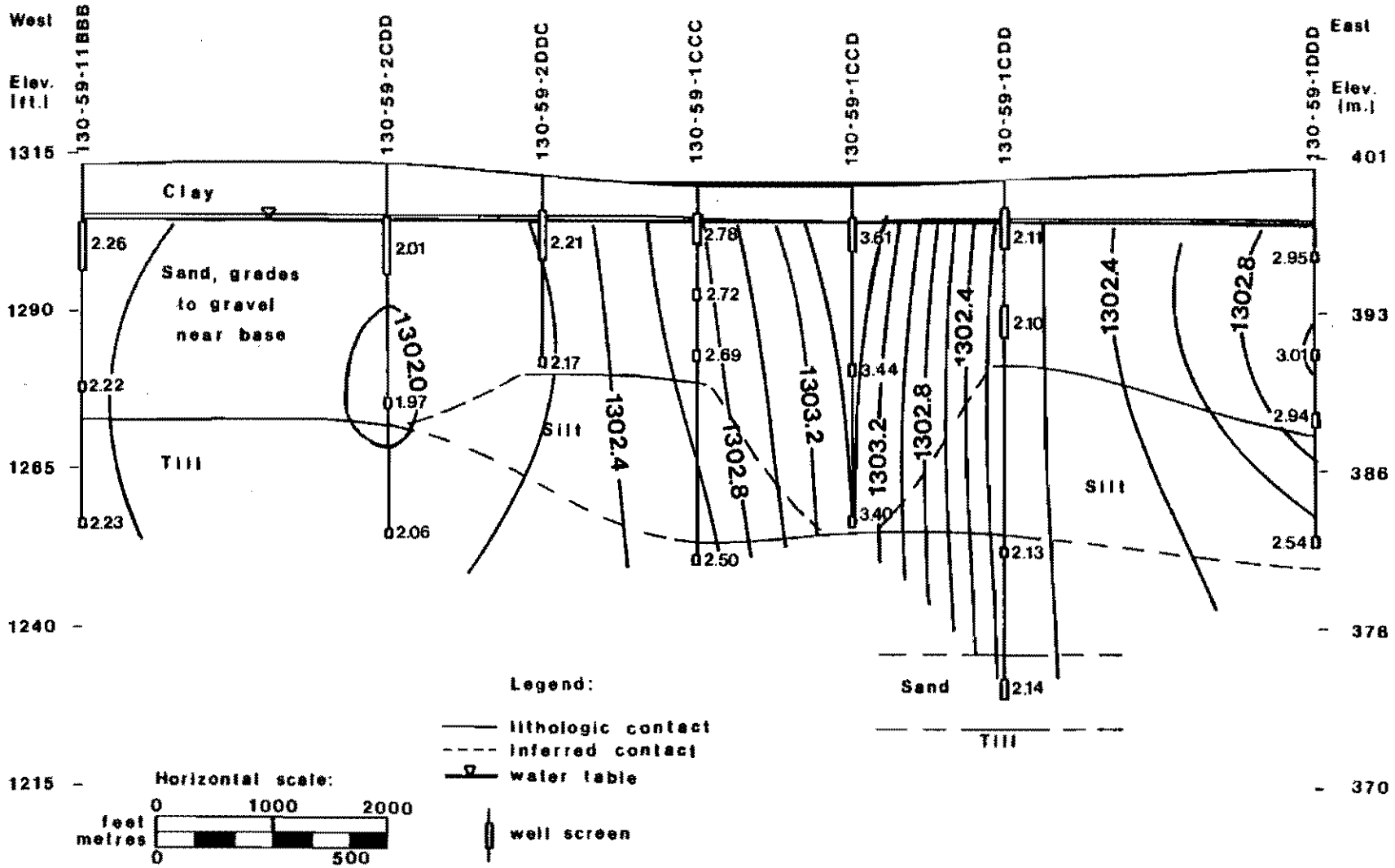

West
East
Elev. (ft.)
Elev. (m.)
130-59-11BBB
130-59-2CDD
130-59-2DDC
130-59-1CCC
130-59-1CCD
130-59-1CDD
130-59-1DDD
1315
1290
1265
1240
1215
401
393
386
378
370
Clay
Sand, grades to gravel near base
Till
Silt
Sand
1301.7
1301.6
1301.8
1301.9
1302.0
1.72
1.73
1.73
1.70
1.72
1.69
2.07
1.67
1.68
2.07
1.68
1.64
1.62
1.71
2.02
1.69
1.71
1.80
1.59
1.55
1.76
1.89
1.95
Legend:
lithologic contact
inferred contact
water table
well screen
Horizontal scale:
feet
metres
0
1000
2000
500

Figure 33. East-west hydraulic heads for March 29, 1984.


West
East
Elev. (ft.)
Elev. (m.)
130-59-11BBB
130-59-2CDD
130-59-2DDC
130-59-1CCC
130-59-1CCD
130-59-1CDD
130-59-1DDD
1315
1290
1265
1240
1215
401
393
386
378
370
Clay
Sand, grades to gravel near base
Till
Silt
Sand
Till
2.26
2.01
2.21
2.78
3.61
2.11
2.72
2.10
2.95
3.01
2.94
2.54
2.22
2.17
2.69
3.44
1.97
2.23
2.06
2.50
3.40
2.13
2.14
1302.0
1302.4
1302.8
1303.2
Legend:
lithologic contact
inferred contact
water table
well screen
Horizontal scale:
feet
metres
0
1000
2000
500

the center of the depression. The mound was confined by the till hills in the east and unconfined to the west, with the major component of flow to the west at that time (Figures 34 and 35). By June 4 the groundwater mound had nearly dissipated, as indicated by wider-spaced hydraulic head contours (Figure 36). The vertical gradient between the upper and lower aquifers reversed from downward to upward.

The hydraulic gradients were greatest during the 1984 spring recharge event around the April 17 measurement period (Figure 34). The horizontal gradient from 130-59-1CCC to 130-59-2CDD is 2.47 feet (0.75 m) over 0.5 miles (805 m) or $9.4X10^{-4}$. The vertical gradient between the two aquifers is $7.4X10^{-2}$ (assuming equal head in the lower aquifer).

A simple formula was employed (Freeze and Cherry, 1979, p.71) to determine the average linear velocity of the groundwater during the recharge event:

$$v = -K/n\ (dh/dl),$$

where v is the average linear velocity, K is the hydraulic conductivity, n is the porosity, and dh/dl is the groundwater gradient. The average linear velocity for the groundwater, on April 17 between 130-59-1CCC and 130-59-2CDD was determined to be $8.2X10^{-6}$ ft/s ($2.5X10^{-4}$ cm/s) (assuming K = $7.9X10^{-2}$ cm/s, n = 0.3, and dh/dl = $9.4X10^{-4}$). Using this formula, over a period of 30 days, at the assumed gradient, the distance traveled would be 21 feet (6.5 m).

The average linear velocity for the intervening till between the two aquifers was determined to be $6.3X10^{-6}$ feet/second ($1.9X10^{-6}$ m/s) (assuming K = $7.8X10^{-4}$ cm/s, n = 0.3, and dh/dl = $7.4X10^{-2}$). Using this

Figure 34. East-west hydraulic heads for April 17, 1984.

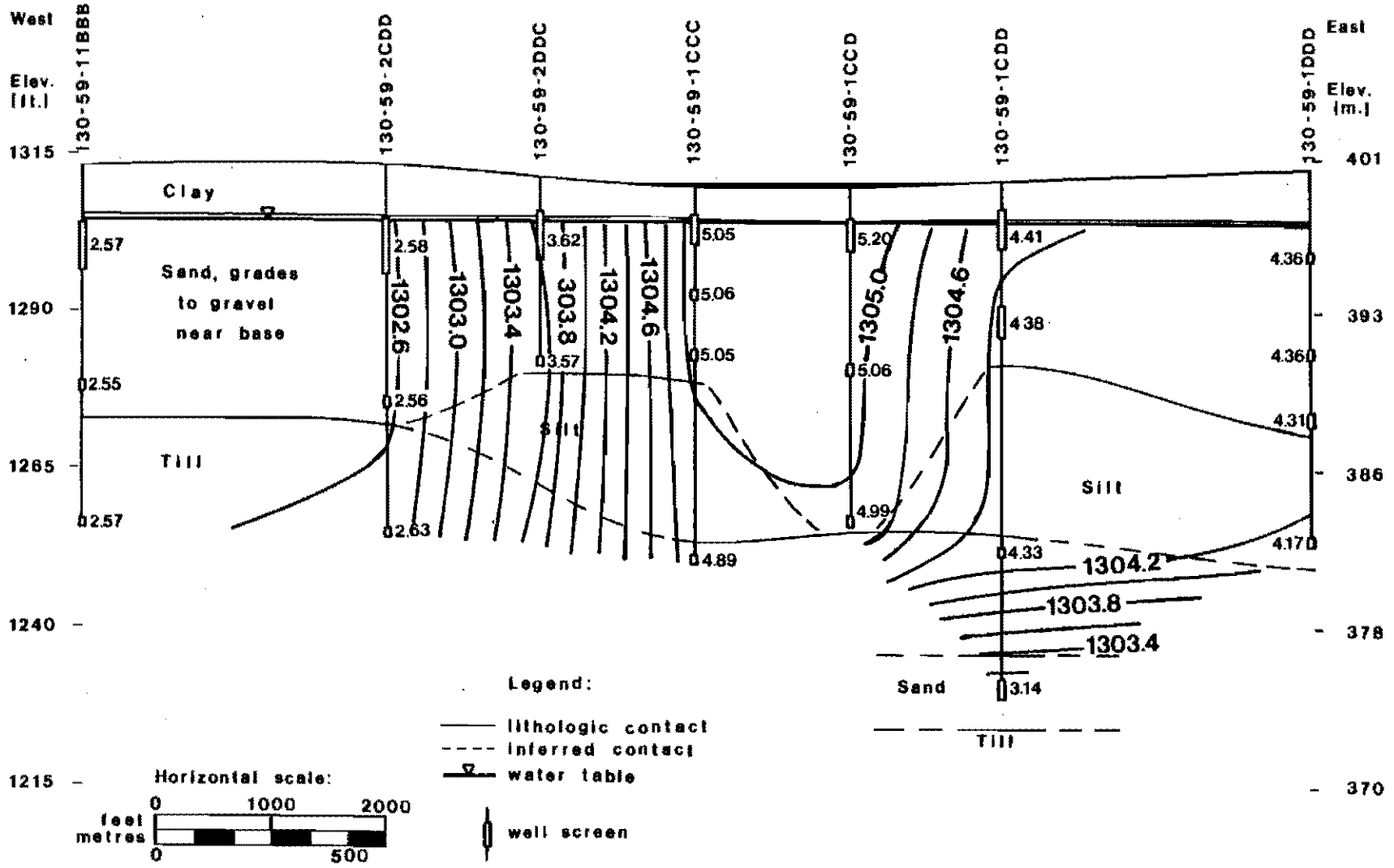

West
East
Elev. (ft.)
Elev. (m.)
130-59-11BBB
130-59-2CDD
130-59-2DDC
130-59-1CCC
130-59-1CCD
130-59-1CDD
130-59-1DDD
1315
1290
1265
1240
1215
401
393
386
378
370
Clay
Sand, grades to gravel near base
Till
Silt
Sand
Till
2.57
2.58
3.62
5.05
5.20
4.41
4.36
2.55
2.56
3.57
5.06
5.05
5.06
4.38
4.36
4.31
2.57
2.63
4.89
4.99
4.33
4.17
3.14
1302.6
1303.0
1303.4
303.8
1304.2
1304.6
1305.0
1304.6
1304.2
1303.8
1303.4
Legend:
lithologic contact
inferred contact
water table
well screen
Horizontal scale:
0
1000
2000
feet
metres
0
500

Figure 35. East-west hydraulic heads for May 15, 1984.

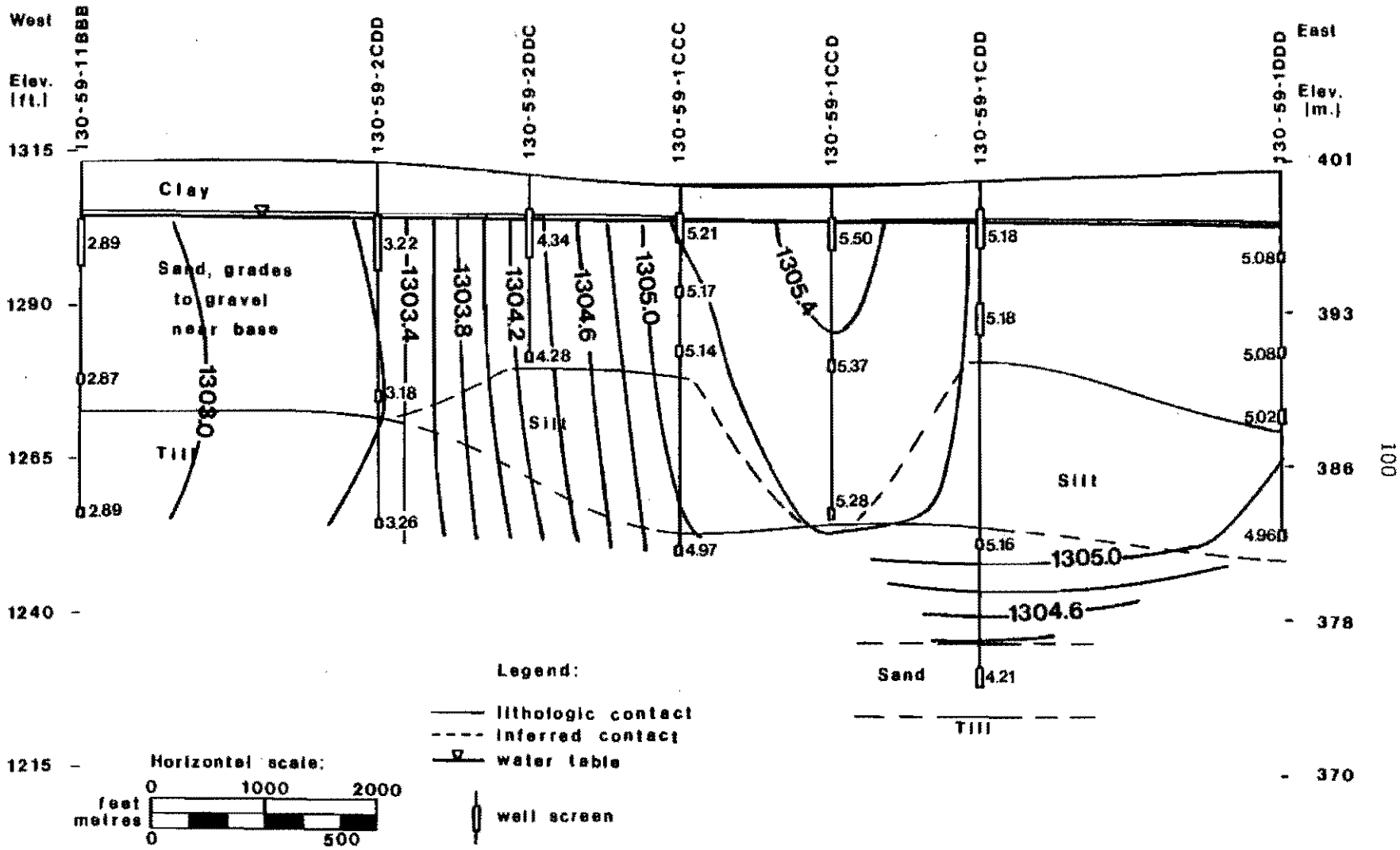
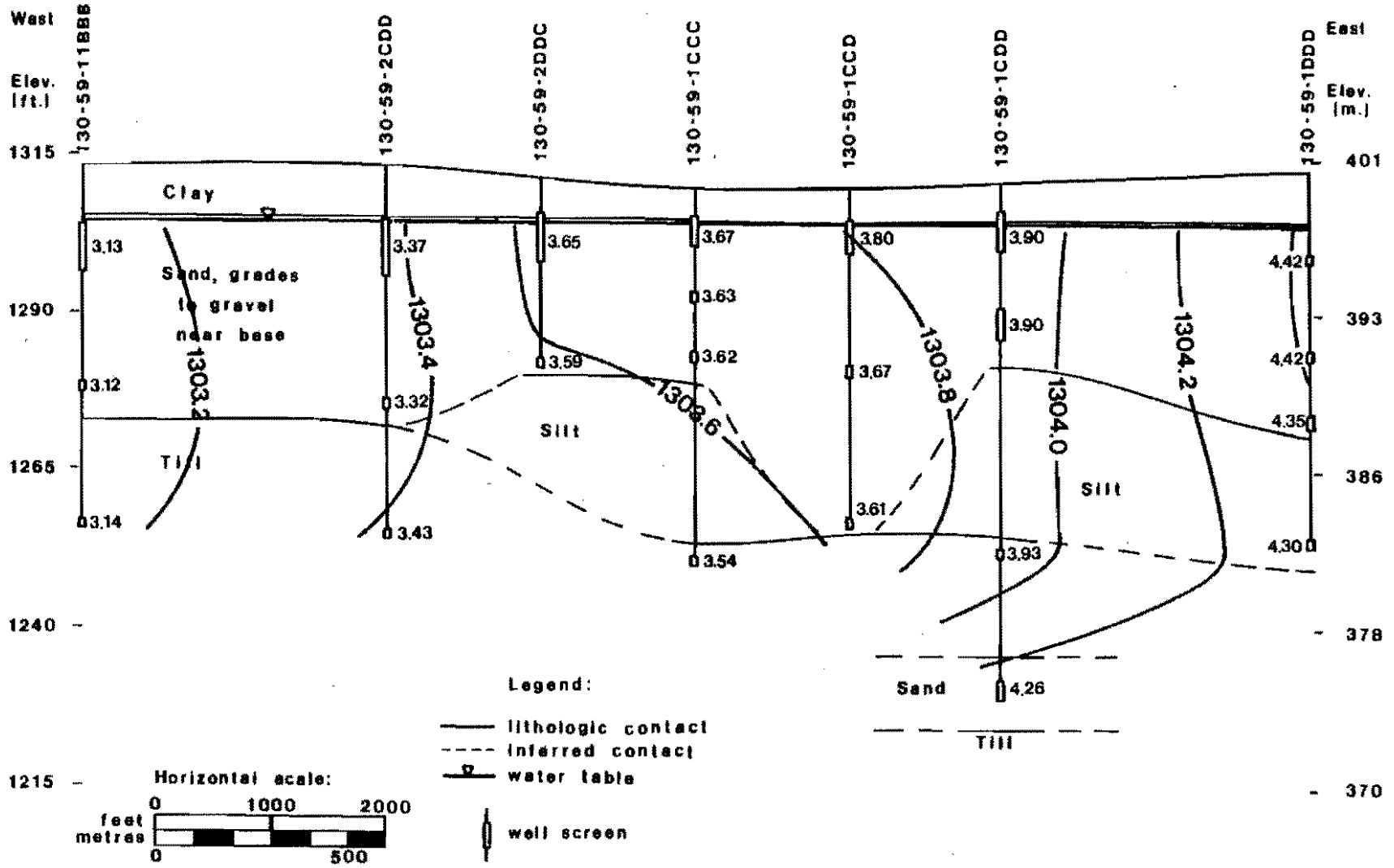

West
East
Elev. (ft.)
Elev. (m.)
130-59-11BBB
130-59-2CDD
130-59-2DDC
130-59-1CCC
130-59-1CCD
130-59-1CDD
130-59-1DDD
1315
1290
1265
1240
1215
401
393
386
378
370
Clay
Sand, grades to gravel near base
Till
Silt
Sand
Till
2.89
3.22
4.34
5.21
5.50
5.18
5.080
5.17
5.18
5.080
5.14
5.37
5.02
2.87
3.18
4.28
5.28
2.89
3.26
4.97
5.16
4.960
4.21
1303.4
1303.8
1304.2
1304.6
1305.0
1305.4
1308.0
1305.0
1304.6
Legend:
lithologic contact
inferred contact
water table
well screen
Horizontal scale:
feet
metres
0
1000
2000
500

Figure 36. East-west hydraulic heads for June 4, 1984.


West
East
Elev. (ft.)
Elev. (m.)
130-59-11BBB
130-59-2CDD
130-59-2DDC
130-59-1CCC
130-59-1CCD
130-59-1CDD
130-59-1DDD
1315
1290
1265
1240
1215
401
393
386
378
370
Clay
Sand, grades to gravel near base
Silt
Till
Sand
Till
3.13
3.12
3.14
3.37
3.32
3.43
3.65
3.59
3.67
3.63
3.62
3.54
3.80
3.67
3.61
3.90
3.90
3.93
4.42
4.42
4.35
4.30
4.26
1303.2
1303.4
1308.6
1303.8
1304.0
1304.2
Legend:
lithologic contact
inferred contact
water table
well screen
Horizontal scale:
feet
metres
0
1000
2000
0
500

formula, over a period of 30 days, at the assumed gradient, the distance traveled would be 16 feet (5.0 m). If flow were to occur between the two aquifers at 130-59-1CDD, where the till is 25 feet (7.6 m) thick, at the calculated velocity a considerable amount of groundwater would be transmitted over a short period of time.

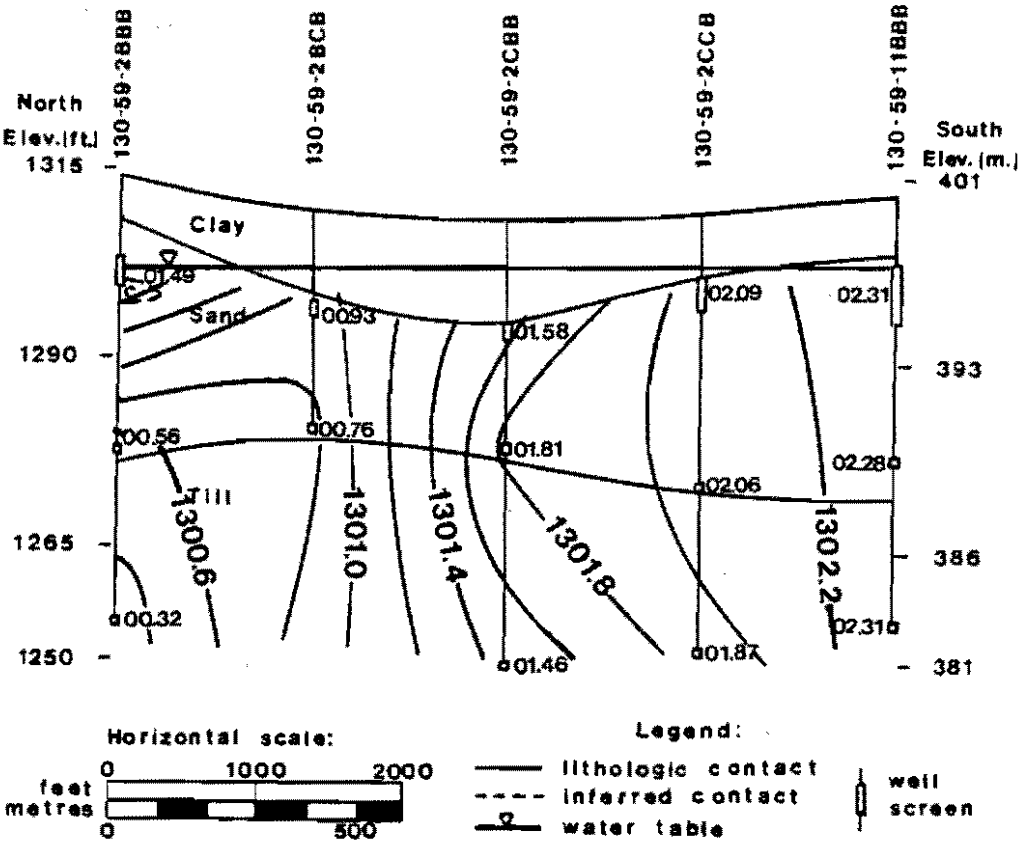
Flow characteristics along the north-south traverse are similar to the seasonal trends illustrated along the east-west traverse. South to north groundwater flow is indicated from August, 1983 to February, 1984 (Figures 37-43). Groundwater moved to an apparent sink, at 130-59-2BBB, through February, 1984. During this period the gradients decreased as indicated by wider-spaced hydraulic head contours. A downward gradient existed at 130-59-2BBB throughout the period.

The start of the spring recharge event, along the north-south traverse, created outward and downward flow as indicated by higher hydraulic head values in the center of the traverse (Figure 44). The maximum gradient between 130-59-2CBB and 130-59-2BCB had a value of $5.8X10^{-4}$. The gradient along the east-west traverse was nearly twice that along the north-south traverse.

The recharge event became more obvious in April and May (Figures 45 and 46). Through these two months the gradients were lower, as indicated by wider-spaced hydraulic head contours. An upward gradient existed at 130-59-2BBB and downward gradients existed over the rest of the traverse except at 130-59-11BBB where hydraulic head values were nearly equal. By June 4 south to north flow had nearly returned (Figure 47). Downward gradients existed along the entire traverse except at 130-59-11BBB.

Figure 37. North-south hydraulic heads for August 27, 1983.

Figure 38. North-south hydraulic heads for September 28, 1983.


North
Elev.(ft.)
1315
1290
1265
1250
South
Elev.(m.)
401
393
386
381
130-59-28BB
130-59-28CB
130-59-2CBB
130-59-2CCB
130-59-11BBB
Clay
Sand
Till
01.49
00.93
01.58
02.09
02.31
00.56
00.76
01.81
02.06
02.28
00.32
01.46
01.87
02.31
1300.6
1301.0
1301.4
1301.8
1302.2
Horizontal scale:
feet
metres
0
1000
2000
500
Legend:
lithologic contact
inferred contact
water table
well screen

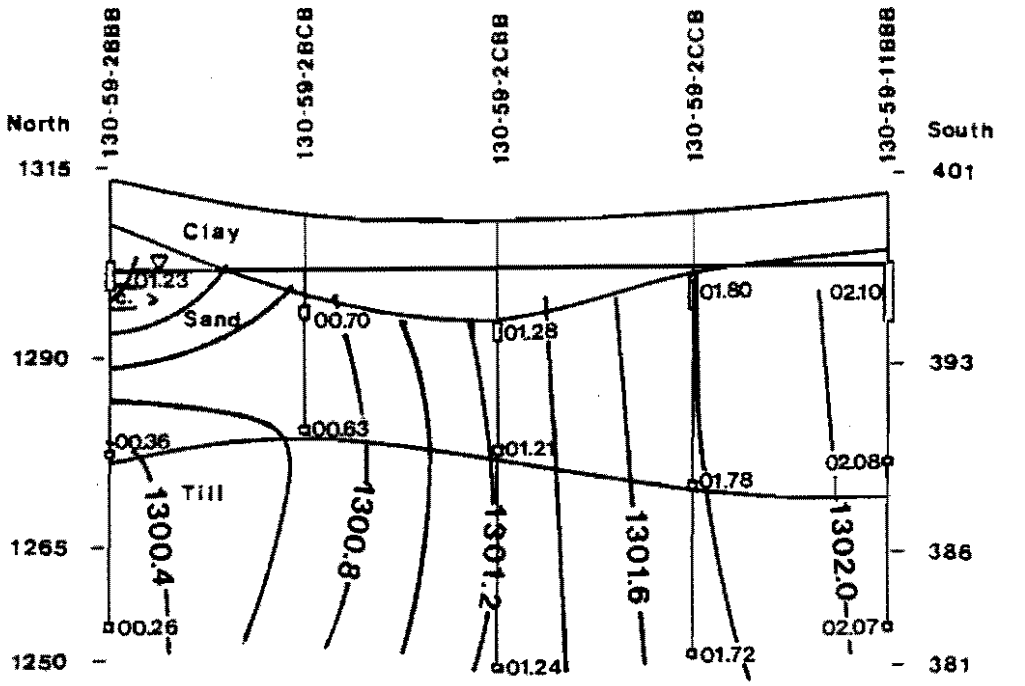
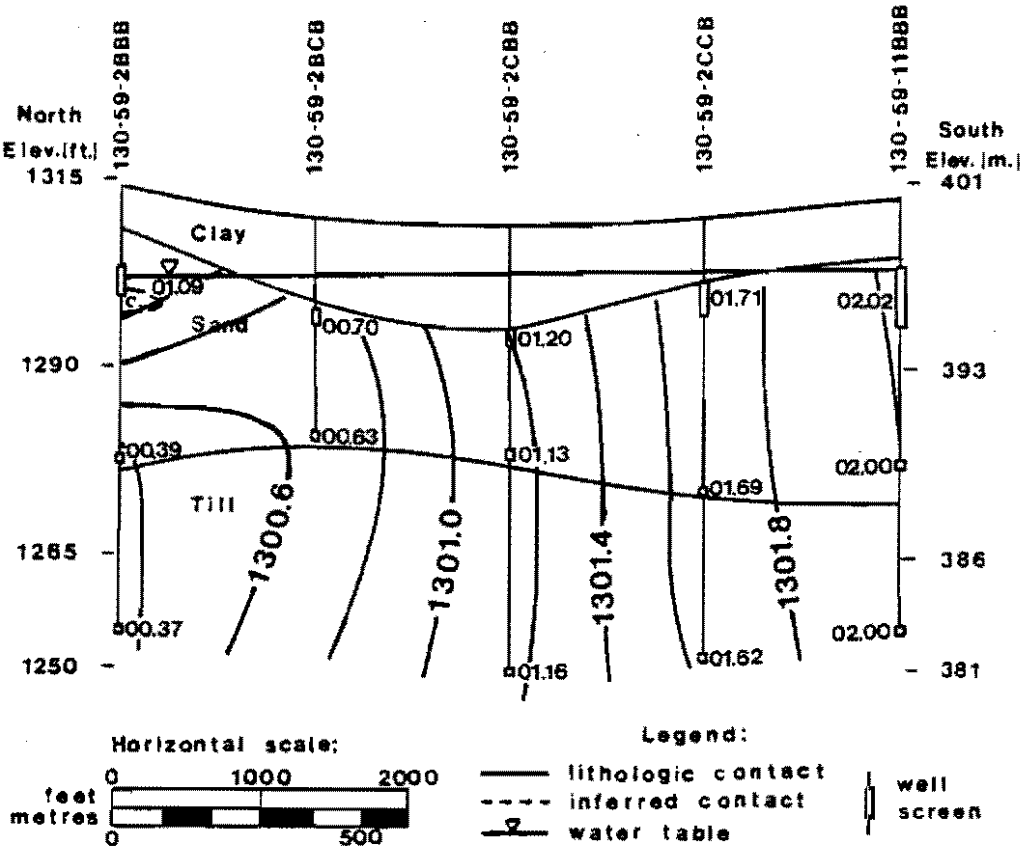

North
1315
1290
1265
1250
South
401
393
386
381
130-59-28BB
130-59-28CB
130-59-2CBB
130-59-2CCB
130-59-11BBB
Clay
Sand
Till
01.23
00.70
01.28
01.80
02.10
00.36
00.63
01.21
01.78
02.08
00.26
01.24
01.72
02.07
1300.4
1300.8
1301.2
1301.6
1302.0

Figure 39. North-south hydraulic heads for October 28, 1983.

Figure 40. North-south hydraulic heads for November 25, 1983.


North
Elev.(ft.)
1315
1290
1265
1250
130-59-2BBB
130-59-2BCB
130-59-2CBB
130-59-2CCB
130-59-11BBB
South
Elev.(m.)
401
393
386
381
Clay
Sand
Till
01.09
00.70
01.20
01.71
02.02
00.39
00.63
01.13
01.69
02.000
00.37
01.16
01.62
02.00
1300.6
1301.0
1301.4
1301.8
Horizontal scale:
feet
metres
0
1000
2000
500
Legend:
lithologic contact
inferred contact
water table
well screen

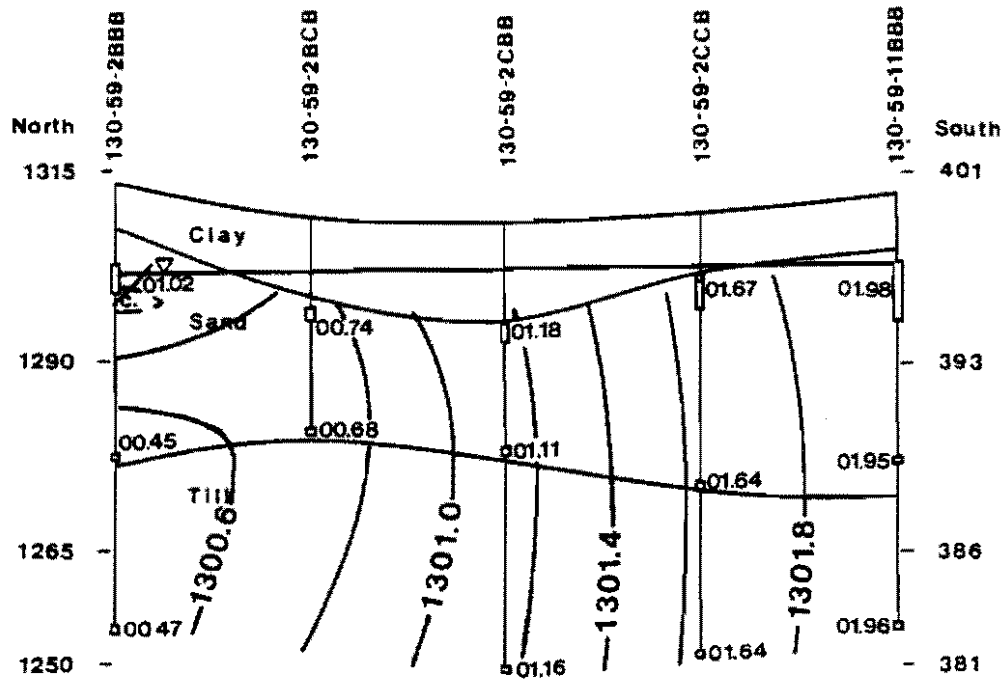
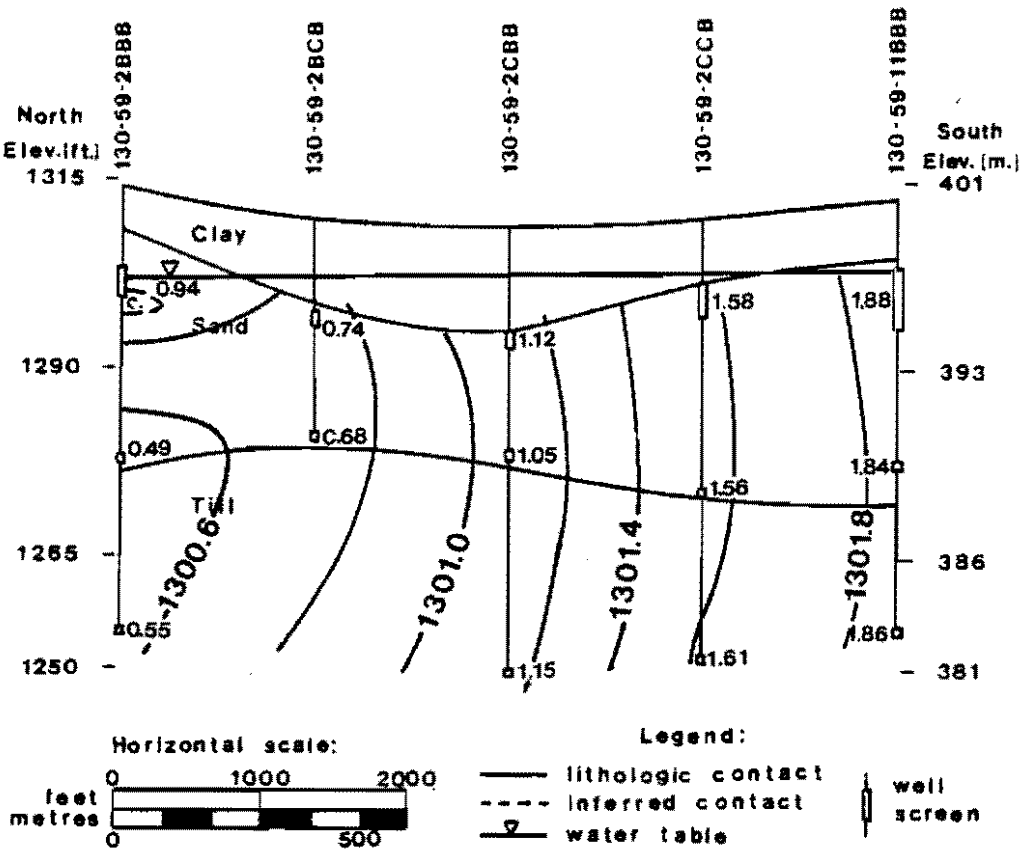

North
1315
1290
1265
1250
130-59-2BBB
130-59-2BCB
130-59-2CBB
130-59-2CCB
130-59-11BBB
South
401
393
386
381
Clay
Sand
Till
01.02
00.74
01.18
01.67
01.98
00.45
00.68
01.11
01.64
01.95
00.47
01.16
01.64
01.96
1300.6
1301.0
1301.4
1301.8

Figure 41. North-south hydraulic heads for January 6, 1984.

Figure 42. North-south hydraulic heads for February 2, 1984.


North
Elev.(ft.)
1315
1290
1265
1250
130-59-2BBB
130-59-2BCB
130-59-2CBB
130-59-2CCB
130-59-11BBB
South
Elev. (m.)
401
393
386
381
Clay
Sand
Till
0.94
0.74
1.12
1.58
1.88
0.49
0.68
1.05
1.56
1.84
0.55
1.15
1.61
1.86
1300.6
1301.0
1301.4
1301.8
Horizontal scale:
feet
metres
0
1000
2000
500
Legend:
lithologic contact
inferred contact
water table
well screen

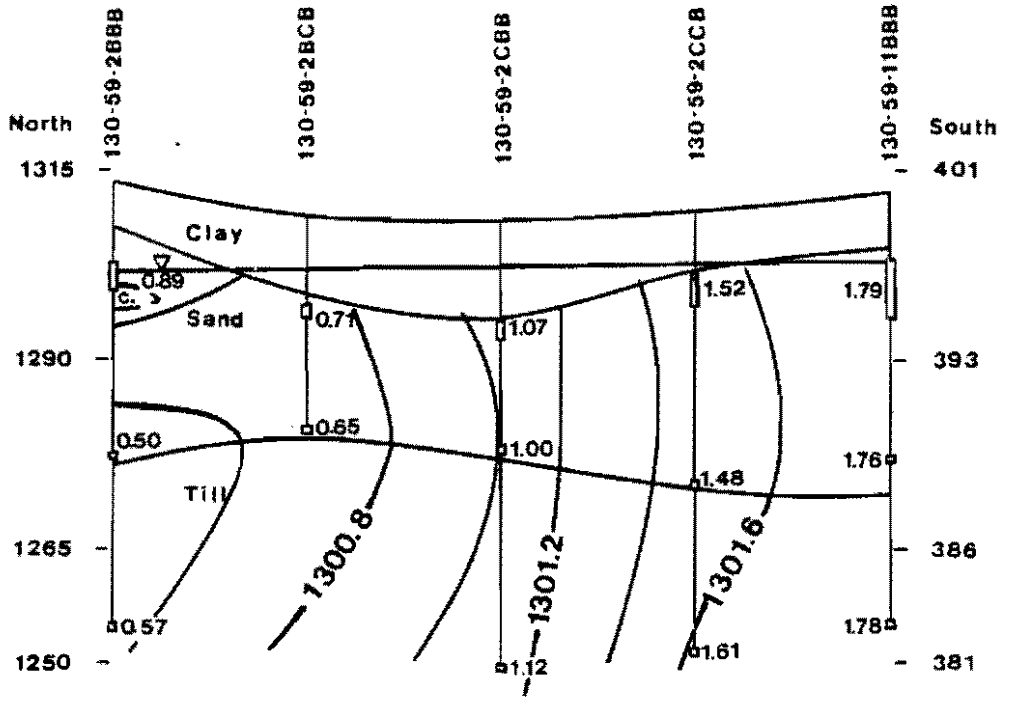
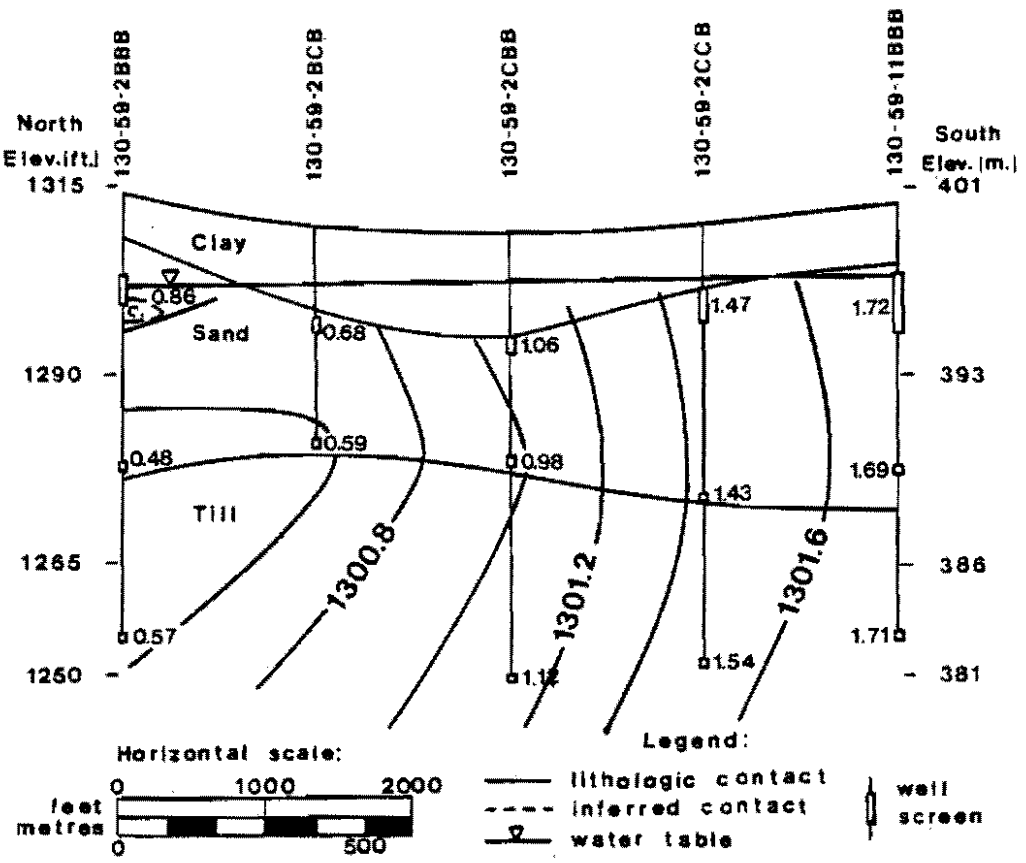

North
1315
1290
1265
1250
130-59-2BBB
130-59-2BCB
130-59-2CBB
130-59-2CCB
130-59-11BBB
South
401
393
386
381
Clay
Sand
Till
0.89
0.71
1.07
1.52
1.79
0.50
0.65
1.00
1.48
1.76
0.57
1.12
1.61
1.78
1300.8
1301.2
1301.6

Figure 43. North-south hydraulic heads for February 18-26, 1984.

Figure 44. North-south hydraulic heads for March 29, 1984.


North
Elev.(ft.)
1315
1290
1265
1250
130-59-2BBB
130-59-2BCB
130-59-2CBB
130-59-2CCB
130-59-11BBB
South
Elev.(m.)
401
393
386
381
Clay
Sand
Till
0.86
0.68
1.06
1.47
1.72
0.48
0.59
0.98
1.43
1.69
0.57
1.54
1.71
1300.8
1301.2
1301.6
Horizontal scale:
feet
metres
0
1000
2000
500
Legend:
lithologic contact
inferred contact
water table
well screen

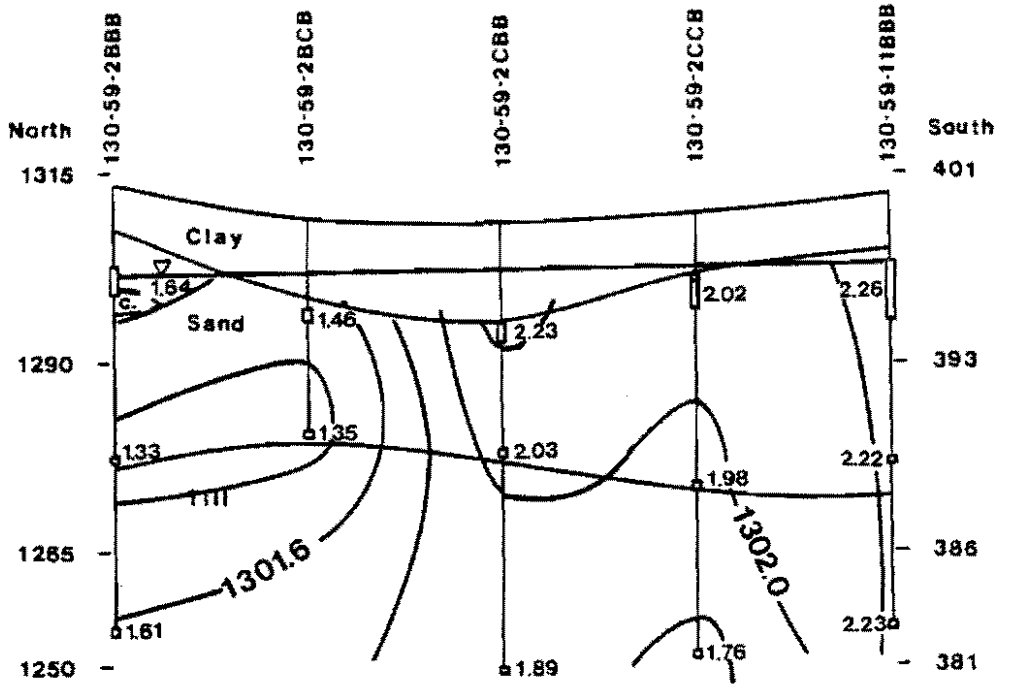
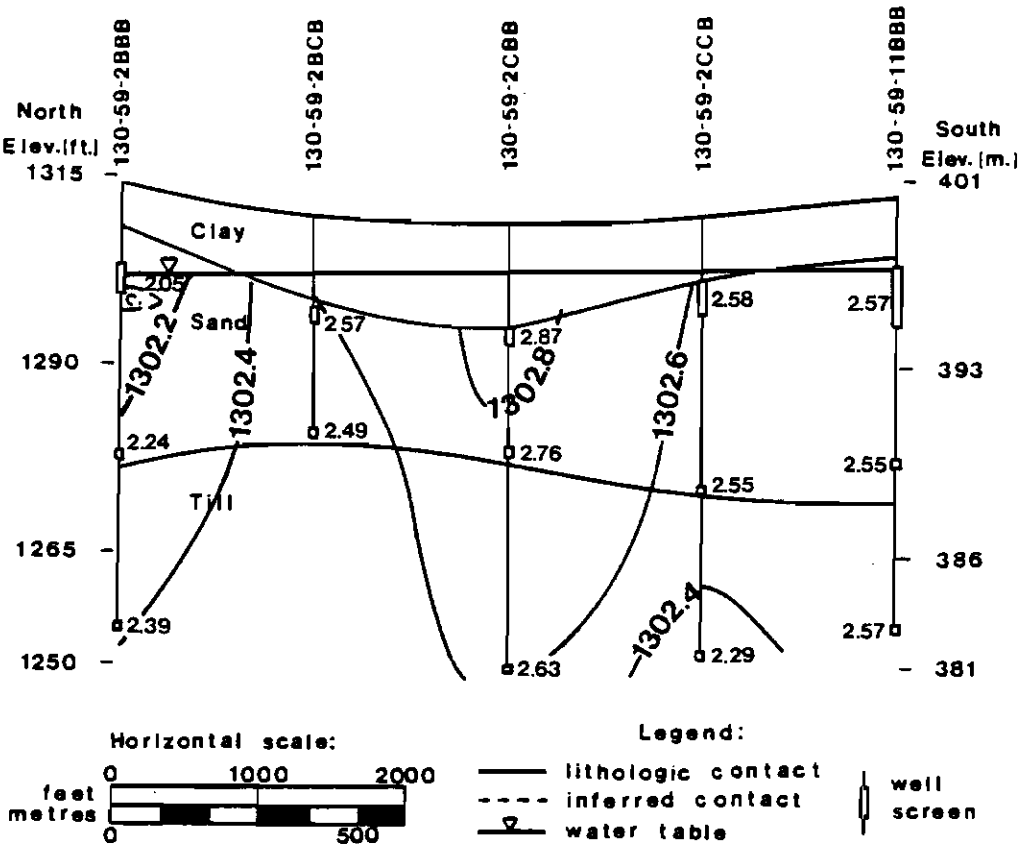

North
1315
1290
1265
1250
130-59-2BBB
130-59-2BCB
130-59-2CBB
130-59-2CCB
130-59-11BBB
South
401
393
386
381
Clay
Sand
Till
1.64
1.46
2.23
2.02
2.26
1.33
1.35
2.03
1.98
2.22
1.61
1.89
1.76
2.23
1301.6
1302.0

Figure 45. North-south hydraulic heads for April 17, 1984.

Figure 46. North-south hydraulic heads for May 15, 1984.


North
Elev.(ft.)
South
Elev.(m.)
130-59-2BBB
130-59-2BCB
130-59-2CBB
130-59-2CCB
130-59-11BBB
1315
1290
1265
1250
401
393
386
381
Clay
Sand
Till
2.05
2.57
2.87
2.58
2.57
2.24
2.49
2.76
2.55
2.55
2.39
2.63
2.29
2.57
1302.2
1302.4
1302.8
1302.6
1302.4
Horizontal scale:
0
1000
2000
feet
metres
0
500
Legend:
lithologic contact
inferred contact
water table
well screen

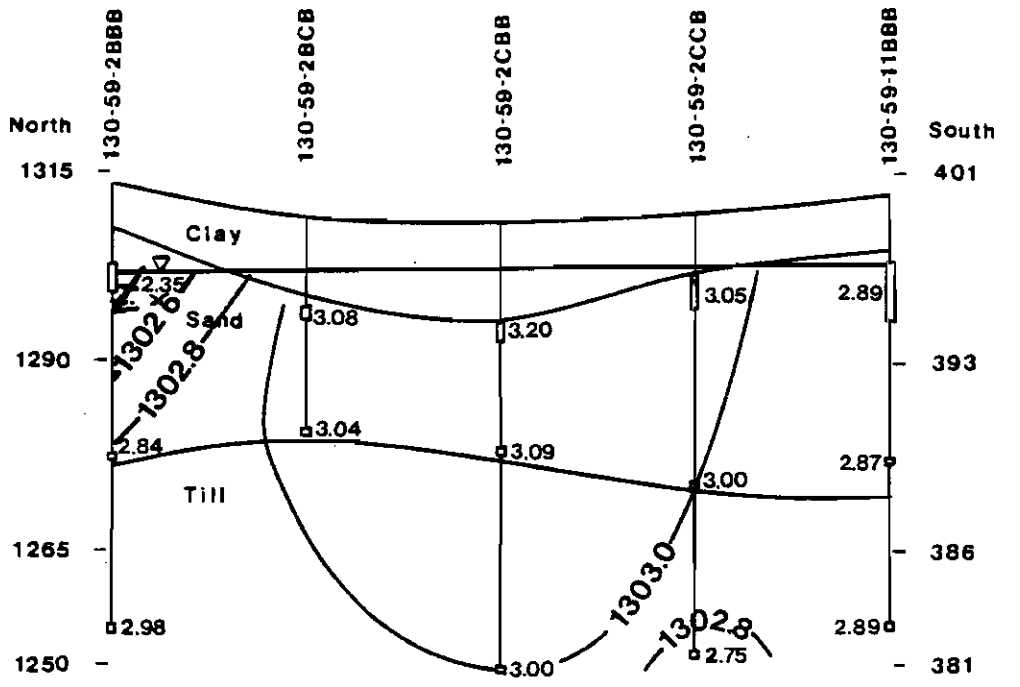
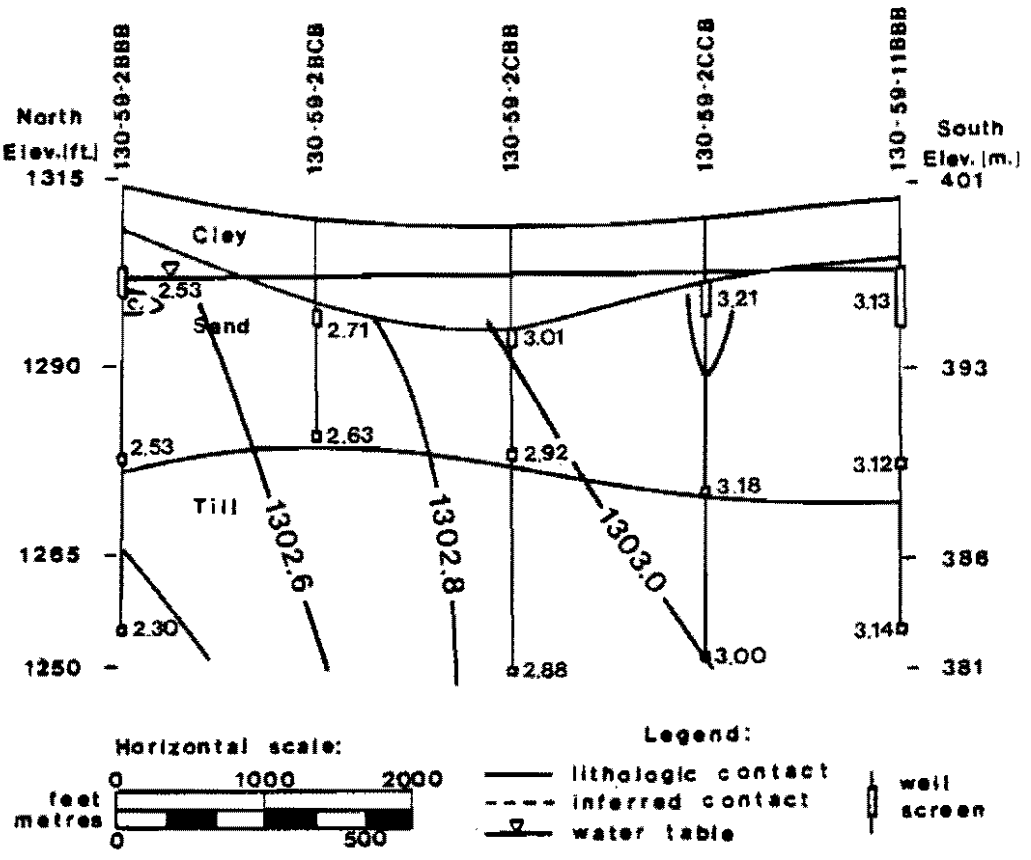

North
South
130-59-2BBB
130-59-2BCB
130-59-2CBB
130-59-2CCB
130-59-11BBB
1315
1290
1265
1250
401
393
386
381
Clay
Sand
Till
2.35
3.08
3.20
3.05
2.89
2.84
3.04
3.09
3.00
2.87
2.98
3.00
2.75
2.89
1302.6
1302.8
1303.0
1302.8

Figure 47. North-south hydraulic heads for June 4, 1984.


North
Elev.(ft.)
1315
1290
1265
1250
South
Elev.(m.)
401
393
386
381
130-59-2BBB
130-59-2BCB
130-59-2CBB
130-59-2CCB
130-59-11BBB
Clay
Sand
Till
2.53
2.71
3.01
3.21
3.13
2.53
2.63
2.92
3.18
3.12
2.30
2.88
3.00
3.14
1302.6
1302.8
1303.0
Horizontal scale:
feet
metres
0
1000
2000
0
500
Legend:
lithologic contact
inferred contact
water table
well screen

Hydraulic head values at the groundwater sinks implied movement of water along the axis of the depression toward the James River. The distance between the sink at 130-59-1CCD and the sink at 130-59-2BBB was 1.60 miles (2.58 km). The maximum hydraulic head difference between these two sites was 2.75 feet (0.84 m) on April 17, 1984. The gradient was therefore $3.26X10^{-4}$. Under the assumptions that the hydraulic conductivity is $7.9X10^{-2}$, n = 0.3, and the gradient were constant, the average linear velocity was then 88.8 feet/year (27.1 m/yr).

Hydraulic heads in the upper part of the aquifer may indicate evapotranspiration (ET). On August 27, 1983, lower hydraulic heads were measured in the center of the north-south traverse indicating an upward gradient (Figure 37). Throughout the remainder of the study, downward gradients were indicated.

Chemical Characteristics

Groundwater Chemical Reactions

A groundwater chemical evolution model proposed for western North Dakota is the basis for interpretation of the chemical evolution of groundwater in the study area (Moran, et al., 1978; Groenewold, et al., 1979 and 1983).

The existing chemical composition of groundwater in this region is the result of an initial composition modified by chemical reactions

between the fluid and the materials through which it moves. The most important reactions occur in the unsaturated zone, through which rainwater and snowmelt move downward toward the water table. A mass balance approach to determine the chemistry of groundwater can be formulated (Drever, 1982, p.140):

Rock + atmospheric input = altered rock + solution.

The major processes determining the chemical characteristics of subsurface waters in the Great Plains will be reviewed here to illustrate their influence on the evolution of groundwater in the study area.

One of the most important controls in a groundwater system is the concentration of hydrogen ions (H^+), or pH. H^+ production within the soil is accomplished by the decomposition of organic matter. Oxygen and organic matter react to produce carbon dioxide, which then reacts with water to form carbonic acid. Carbonic acid (H_2CO_3) dissociates to form H^+ and bicarbonate ions (HCO_3^-) by the reaction:

$$H_2CO_3 = H^+ + HCO_3^-.$$

Bicarbonate ions can further dissociate to form hydrogen and carbonate ions:

$$HCO_3^- = H^+ + CO_3^{2-}.$$

Natural groundwater systems commonly fall within the pH range (6-9) in which the bicarbonate ion is the most abundant form of carbon (Drever, 1982, pp. 35-38).

Another potential source of hydrogen ions is the oxidation of iron sulfides, a process which has been demonstrated to be significant in western North Dakota (Groenewold, et al., 1983, pp. 7-8). This reaction can be stated as:

$$4FeS_2 + 15O_2 + 14H_2O \longrightarrow 4Fe(OH)_3 + 16H^+ + 8SO_4^{2-}.$$

In addition to hydrogen ion production, the oxidation of pyrite also yields sulfate ions and iron hydroxide.

In the presence of hydrogen ions, calcite and dolomite dissolve to produce calcium, magnesium, and bicarbonate ions by the reactions:

$$CaCO_3 + H^+ = Ca^{2+} + HCO_3^- \quad \text{and}$$
$$Ca,Mg(CO_3)_2 + 2H^+ = Ca^{2+} + Mg^{2+} + 2HCO_3^-.$$

Because calcite ($CaCO_3$) is more soluble than dolomite ($Ca,Mg(CO_3)_2$), the concurrent dissolution of both minerals will usually result in greater concentrations of Ca^{2+} than Mg^{2+}.

Another mineral that can contribute Ca^{2+} to groundwater is gypsum. Perhaps more significant is the fact that sulfate (SO_4^{2-}) is also a product of gypsum dissolution as shown in the following reaction:

$$CaSO_4.2H_2O = Ca^{2+} + SO_4^{2-} + 2H_2O .$$

This reaction, like most chemical reactions, is a reversible process; gypsum can precipitate from solution if the right side of the equation has a greater activity product than the equilibrium constant for the dissolution reaction.

The amount of carbon dioxide, or P_{CO2} (partial pressure of carbon dioxide), available to dissolve carbonate minerals is an important geochemical control. An open system, in which CO_2 is continuously supplied by interaction with the soil atmosphere, leads to high values of HCO_3^- and Ca^{2+} (Groenewold, et al., 1983, pp. 11-16). A closed system, in which CO_2 is not replenished, results in lower amounts of HCO_3^- and Ca^{2+} than the open system. Therefore, the initial P_{CO2} and pH are the controlling factors in carbonate mineral dissolution within a closed system.

Water in contact with clay minerals and other substances may undergo an exchange of cations (Drever, 1982, p. 82). The exchange process is driven by a preference of one ion over another (Freeze and Cherry, 1979, pp. 127-134). Ca^{2+} has a stronger affinity for absorption than Mg^{2+}, and K^+ has a stronger affinity for absorption than Na^+. Normally the divalent ions are preferentially adsorbed over the monovalent ions in the exchange process. Montmorillonite is the dominant clay mineral in tills northeast of the study site (Falcone, 1983, p. 108) and Na-Montmorillonite is the dominant clay mineral in the Tertiary sediments in North Dakota (Groenewold, et al., 1983, pp. 18-22). This clay has a large cation exchange capacity (Drever, 1982, p. 82). Water with concentrations of Ca^{2+} and/or Mg^{2+} will exchange for Na^+ on the montmorillonite clay, thereby reducing the Ca^{2+} and/or Mg^{2+} concentration and enriching the water with Na^+.

Dissolution of gypsum or oxidation of pyrite and dissolution of carbonate minerals will yield Ca^{2+} and SO_4^{2-} in solution. If the solution is in equilibrium with respect to gypsum, cation exchange of

Ca^{+} for Na^{+} will cause an undersaturation of gypsum. Further dissolution of gypsum and cation exchange will then yield a Na^{+}, SO_4^{2-} dominated water.

Groundwater Chemical Classification

Chemical analyses from water samples collected at USBR wells on May 30, 1983 were plotted on a Piper-trilinear diagram (Figure 48). The lower right triangle represents the distribution of anions in solution expressed as the percentage of milliequivalents (meq). The triangle is partitioned into four areas, three of which have a dominant anion (SO_4^{2-}, Cl^{-}, and HCO_3^{-}) and a central with no dominant type. The lower left triangle represents the distribution of cations in solution by percentage meq. This triangle is also partitioned into four areas, three of which have a dominant cation (Ca^{2+}, Mg^{2+}, and $Na^{+} + K^{+}$) and a central with no dominant type. The third diagram, a diamond, combines the anion and cation data onto one diagram. The analyses plotted in the diamond are classified as calcium-magnesium bicarbonates, calcium-magnesium sulfates and sodium sulfates. A large proportion of the water is in the no-dominant range of cations and can be classified as calcium-magnesium-sodium bicarbonate and sulfate types.

Chemical analyses of water samples collected from the NDSWC wells in September, 1983 were also plotted on a trilinear diagram (Figure 49). The samples are further classified by depth on the diagram. The shallow water (5-20 feet/1.5-6.1 m) across the two traverses can be classified as calcium-magnesium bicarbonate, sodium bicarbonate, calcium-magnesium sulfate, and sodium sulfate. The intermediate water (28-42

Figure 48. Piper-trilinear diagram of USBR wells sampled May 30, 1983.

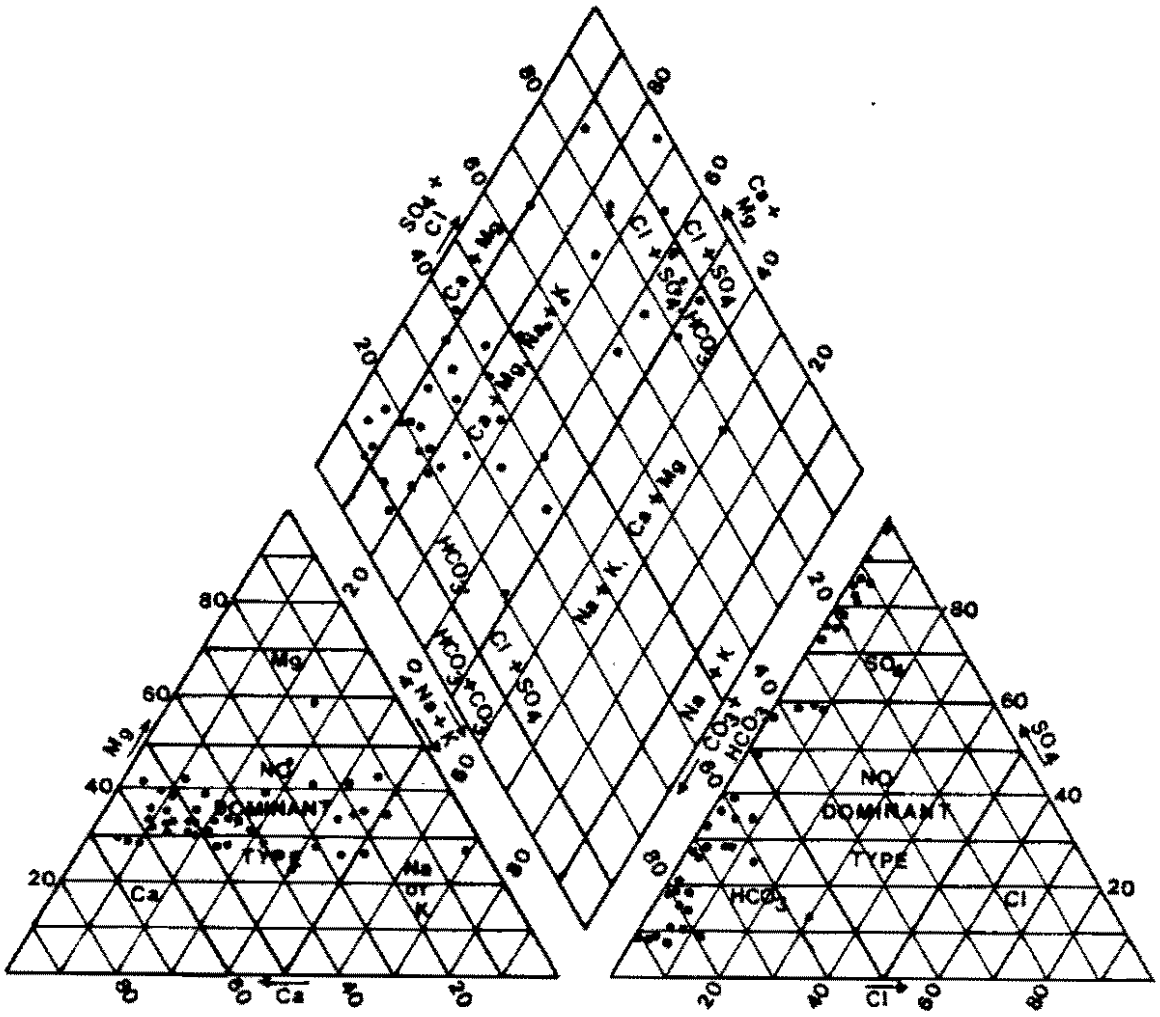
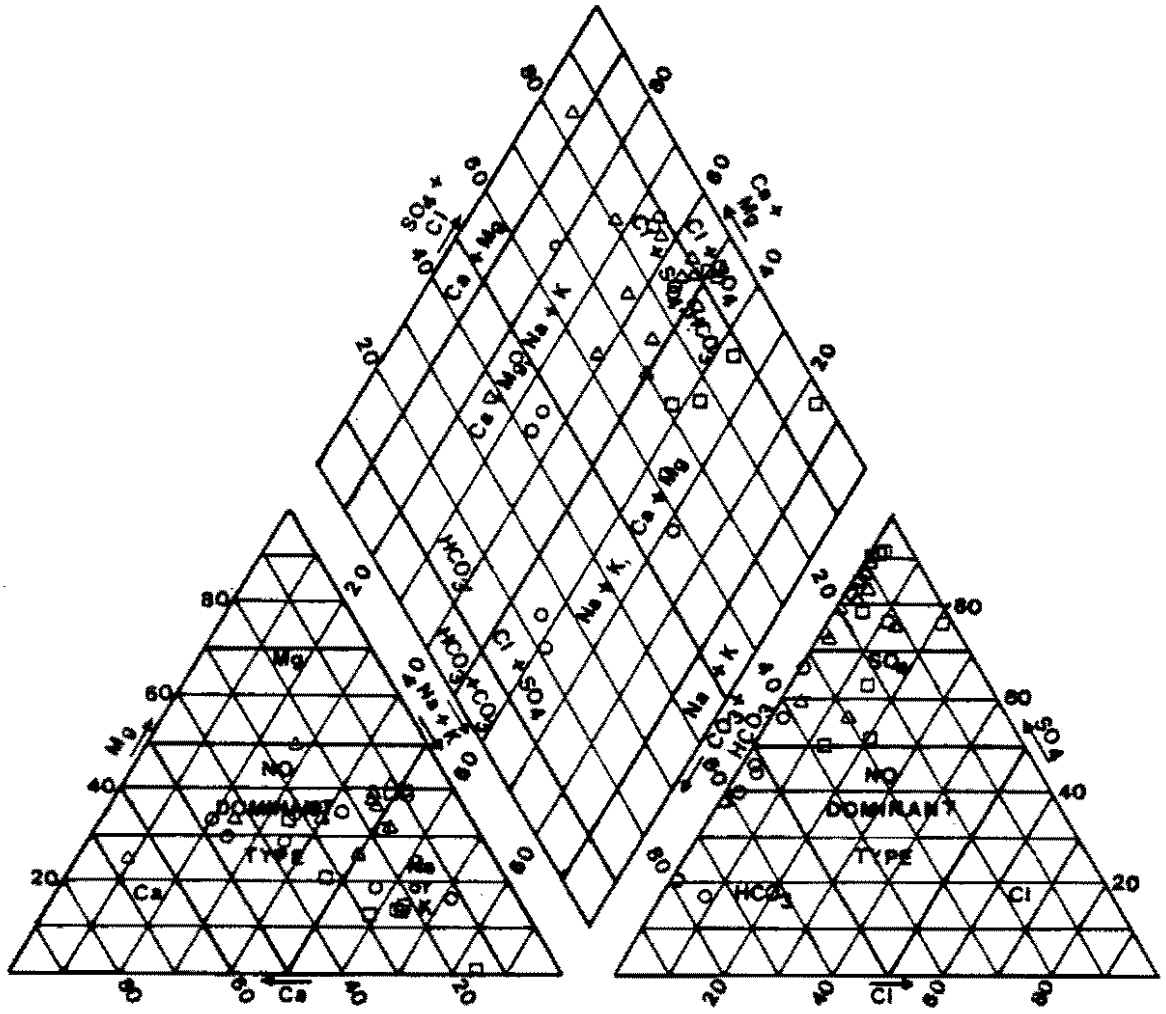

Mg
Na or K
Ca
Cl
SO4
HCO3+CO3
Ca+Mg
Na+K
Ca+Mg
Cl+SO4
Cl+SO4
HCO3+CO3
Na+K
Ca+Mg
Cl+SO4
HCO3+CO3
Na+K
CO3+HCO3
SO4
Cl
DOMINANT
TYPE
DOMINANT
TYPE
HCO3
Cl
20
40
60
80

Figure 49. Piper-trilinear diagram of NDSWC wells sampled September, 1983.



KEY:

○ Shallow wells, 5-20 ft. (1.5-6.1 m)

△ Intermediate wells, 28-42 ft. (8.5-12.8 m)

□ Deep wells, 53-60 ft. (16.2-18.3 m)

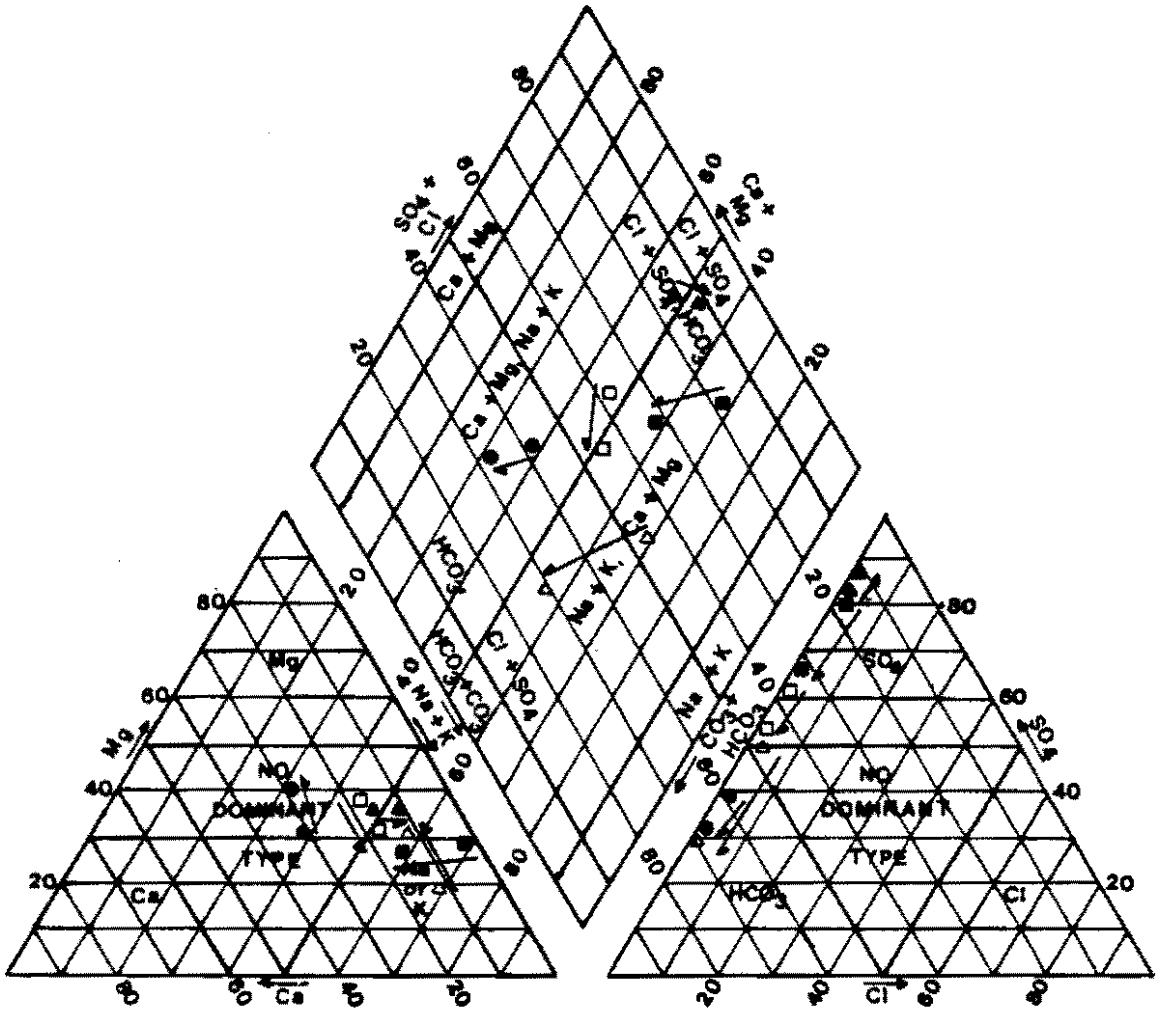
feet/8.5-12.8 m) is characterized mainly as calcium-magnesium sulfate with one well as sodium sulfate and one well as calcium-magnesium bicarbonate. The deep water (53-60 feet/16.2-18.3 m) is mainly calcium-magnesium sulfate or sodium sulfate. Typically, the water changes from a calcium-magnesium bicarbonate type to a sodium sulfate type with increasing depth.

To determine the impact of a recharge event on water chemistry, selected shallow wells of the USBR and NDSWC were plotted on a Piper diagram (Figure 50). The five wells selected had the greatest change in water chemistry from the February to the April sampling periods. The change in water type is indicated with an arrow from the February sample to the April sample. Three of the wells, USBR-22, NDSWC-12279, and NDSWC-12304, had parallel changes toward the calcium-magnesium bicarbonate corner of the diamond diagram. One well, NDSWC-12286, moved toward the sodium bicarbonate corner and the last well, USBR-135, moved toward the sodium sulfate corner. In the first four cases the TDS levels decreased, as would be expected with fresh water infiltrating into the system. The last case, USBR-135, actually increased in TDS from 4320 mg/L to 6040 mg/L.

Distribution of Total Dissolved Solids

The values of TDS, as determined by the NDSWC laboratory, are plotted on the surficial map and on cross-sections representing the two traverses (Figures 51-59). Lines of equal concentration of dissolved solids were drawn illustrating the distribution of TDS. The distribution of the near-surface brackish groundwater is shown in Figure

Figure 50. Piper-trilinear diagram of selected shallow wells indicating water-type changes from February to April, 1984.



Symbol / Well number

△ / NDSWC - 12279

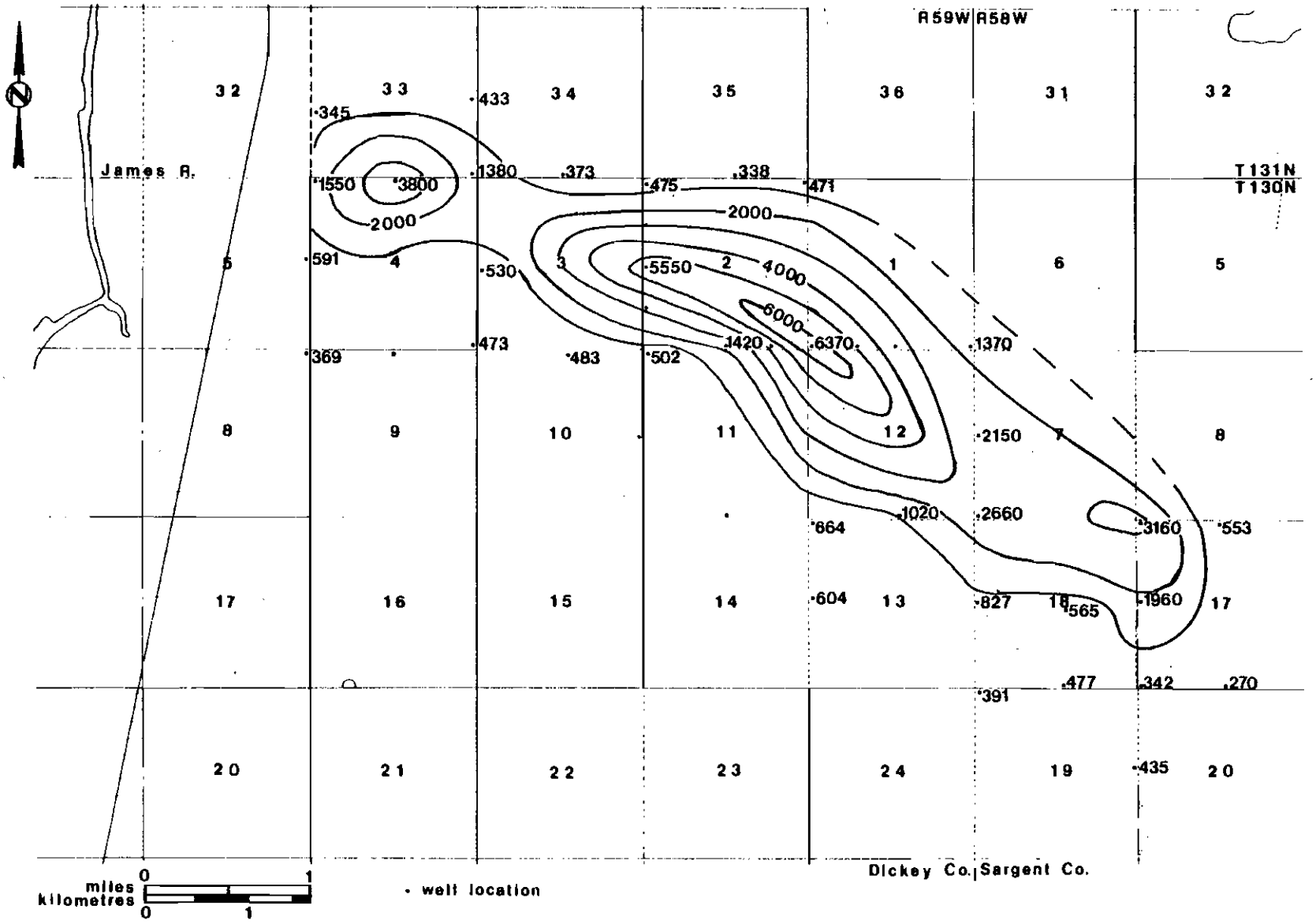
□ / NDSWC - 12286

● / NDSWC - 12304

■ / USBR - 22

▲ / USBR - 135

Figure 51. Horizontal extent of the near surface brackish groundwater (May-June, 1983).


R59W R58W
T131N
T130N
James R.
32
33
34
35
36
31
32
345
433
1380
373
475
338
471
1550
3800
2000
591
530
5550
4000
6000
6370
1420
369
473
483
502
1370
2150
1020
2660
664
3160
553
604
827
565
1960
17
391
477
342
270
435
20
21
22
23
24
19
20
Dickey Co.
Sargent Co.
miles
kilometres
0
1
well location

51. The brackish water parallels the topographic depression (Figure 7), the surficial clay deposits (Figure 11), and the saline soils (Figure 3).

Vertical differences in TDS are illustrated in two observation wells. Prior to the July, 1983 recharge event observation well USBR 204C, (130-58-17BBB), screened in the surficial clay, contained water with a TDS value of 12,700 mg/L. The water in the aquifer, directly underlying the clay, had a TDS concentration of 3,160 mg/L. Before additional water samples could be collected during the next sampling period the two wells were destroyed by vandals. The potential effects of mixing these two types of water will be discussed in a later section.

The TDS distribution along the east-west traverse in September, 1983 is shown in Figure 52. Relatively fresh water is located along the surface of the aquifer except at 130-59-1CDD, where a slight upward gradient was present throughout the fall of 1983 and the winter of 1984. Because two water-table wells (130-59-2DDC and 130-59-1CCC) could not be sampled in September, the iso-concentration lines are dashed where inferred. The highest concentration of TDS is within the till near the center of the depression (130-59-1CCC). The highest concentration of TDS, within the aquifer, is at the groundwater sink (130-59-1CCD). The TDS concentration is lower in the lower aquifer than in the Oakes aquifer at 130-59-1CDD. A small zone of fresh water, surrounded by brackish water, is at 130-59-1DDD.

The TDS distribution for the October-November, 1984 sampling period is shown in Figure 53. Water samples were collected from the two water table wells not sampled in September. The TDS values plotted from these

Figure 52. TDS distribution along the east-west traverse (September, 1983). Dashed contours indicate inferred positions.

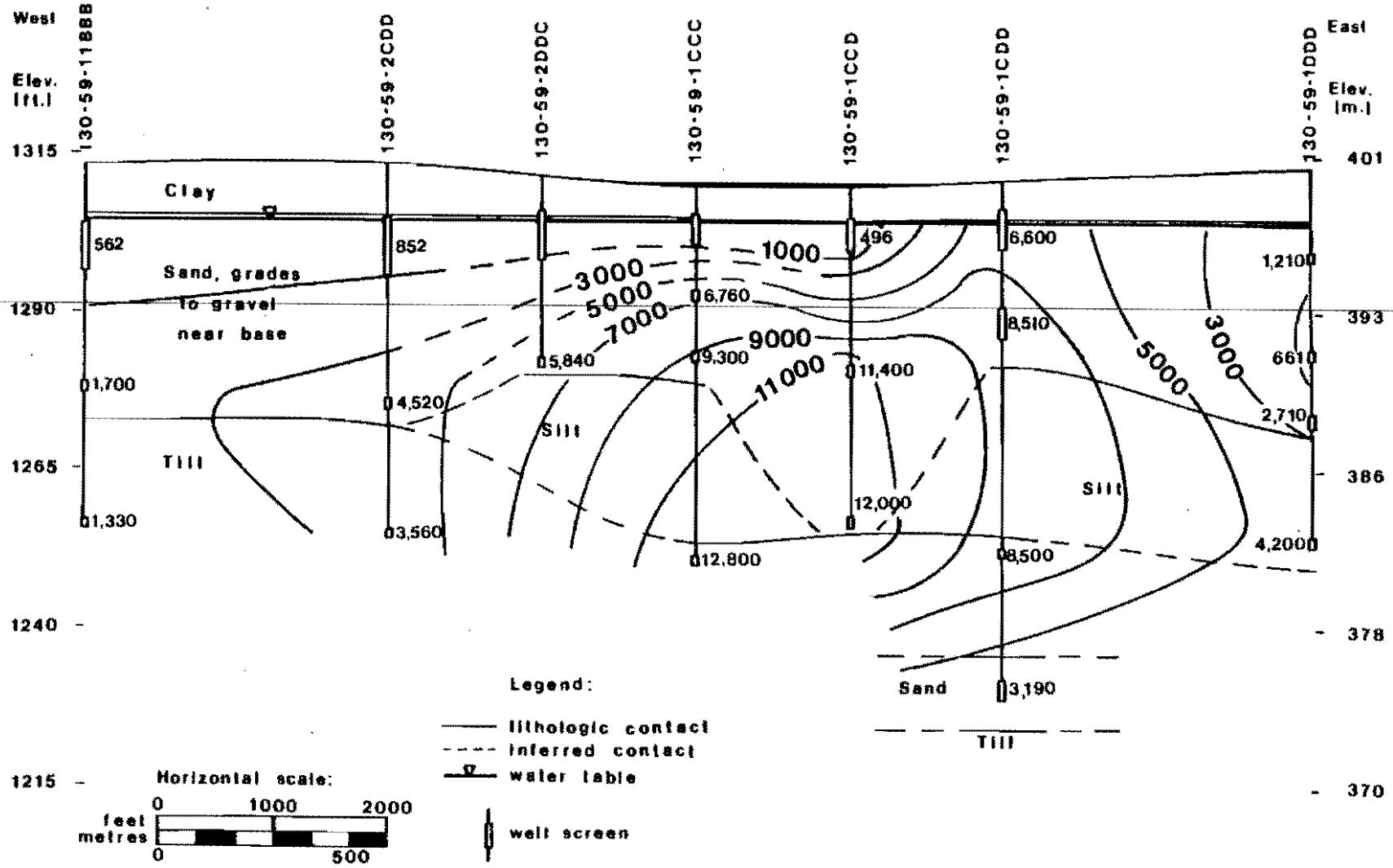
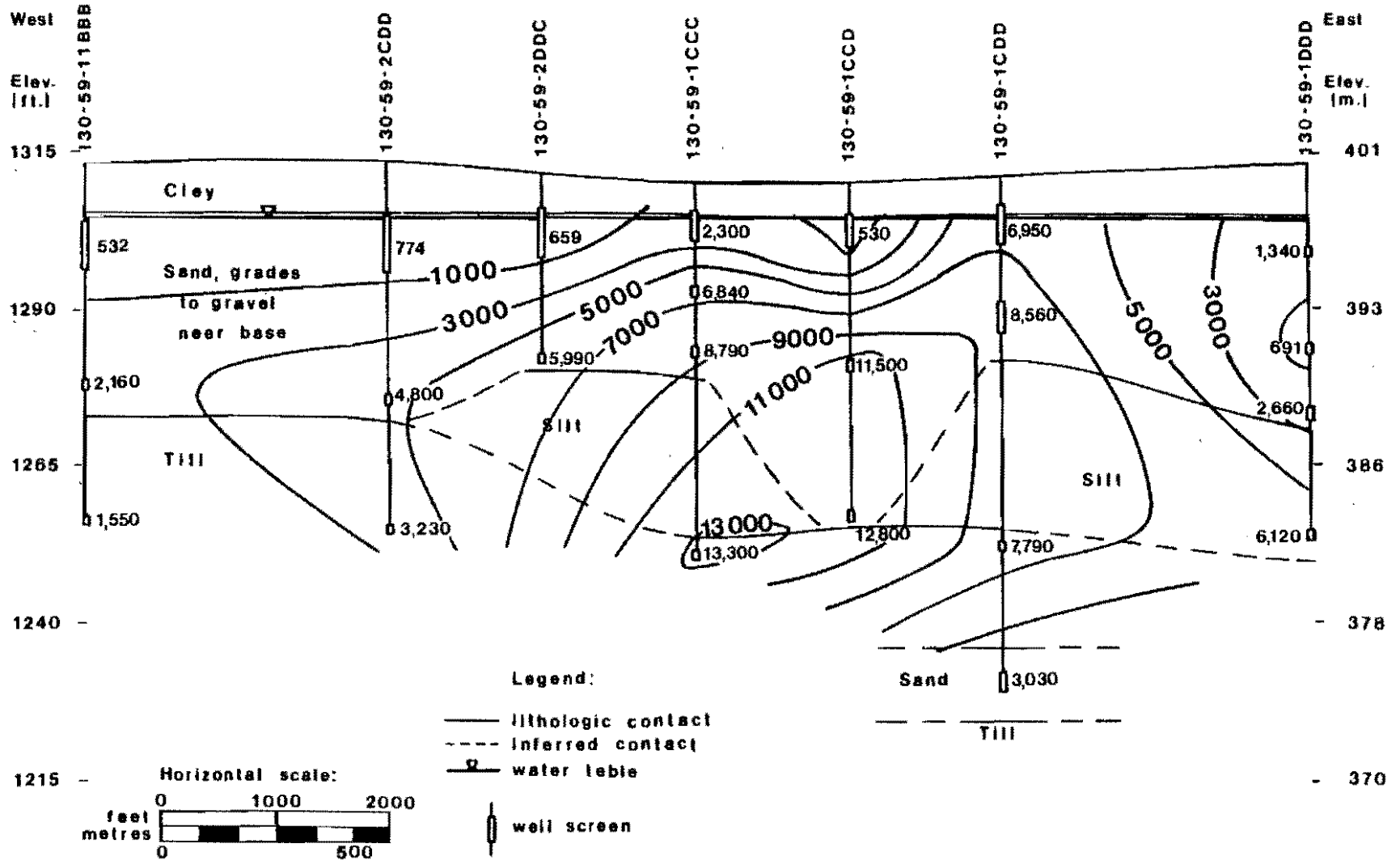

West
East
Elev. (ft.)
Elev. (m.)
130-59-11888
130-59-2CDD
130-59-2DDC
130-59-1CCC
130-59-1CCD
130-59-1CDD
130-59-1DDD
1315
1290
1265
1240
1215
401
393
386
378
370
Clay
562
852
496
6,600
1,2100
Sand, grades to gravel near base
1000
3000
5000
7000
9000
11000
6,760
8,510
6610
1,700
5,840
9,300
11,400
4,520
2,710
Till
Silt
Silt
12,000
1,330
3,560
12,800
8,500
4,2000
Sand
3,190
Till
Legend:
lithologic contact
inferred contact
water table
well screen
Horizontal scale:
feet
metres
0
1000
2000
0
500

Figure 53. TDS distribution along the east-west traverse (October-November, 1983).


West
East
Elev. (ft.)
Elev. (m.)
130-59-11BBB
130-59-2CDD
130-59-2DDC
130-59-1CCC
130-59-1CCD
130-59-1CDD
130-59-1DDD
1315
1290
1265
1240
1215
401
393
386
378
370
Clay
Sand, grades to gravel near base
Till
Silt
Sand
532
774
659
2,300
530
6,950
1,340
2,160
4,800
5,990
6,840
8,790
11,500
8,560
6,910
2,660
1,550
3,230
13,300
12,800
7,790
6,120
3,030
1000
3000
5000
7000
9000
11000
13000
Legend:
lithologic contact
inferred contact
water table
well screen
Horizontal scale:
feet
metres
0
1000
2000
500

two wells illustrates a second mound of brackish water at the water table located at 130-59-1CCC. However, in contrast to the brackish water at 130-59-1CDD, the groundwater at 130-59-1CCC exhibited a slight downward gradient from the fall of 1983 through the winter of 1984.

At several locations, changes in TDS concentrations, greater than 100 mg/L, occurred from the September to the October-November sampling periods. At the water table, changes to higher concentrations occurred at locations 130-59-1CDD and 130-59-1DDD. At the base of the aquifer, every location showed an increase in TDS except at 130-59-1CDD and 130-59-1DDD, where little change occurred, and at 130-59-1CCC where a decrease of 510 mg/L occurred. All of the till/silt wells showed an increase in TDS except at 130-59-2CDD and 130-59-1CDD where a TDS decrease and a slight upward gradient was determined between the two sampling periods. The lower aquifer also showed a decrease in TDS during the same period.

A general decline in TDS occurred from the October-November to the February sampling periods (Figures 53 and 54). Along the east-west traverse the TDS concentrations at the water table either declined or remained nearly the same. At the base of the aquifer TDS either decreased or stayed the same except at 130-59-11BBB and 130-59-1CCC, where increases occurred. In the till/silt wells, the TDS concentrations also decreased or stayed the same. The lower aquifer increased by 420 mg/L over the same period.

TDS changes due to the spring recharge event from February to April, 1984 (Figures 54 and 55) indicated declines in two water-table wells, a slight increase in one, and no change in the others. At

Figure 54. TDS distribution along the east-west traverse (February 18-26, 1984).

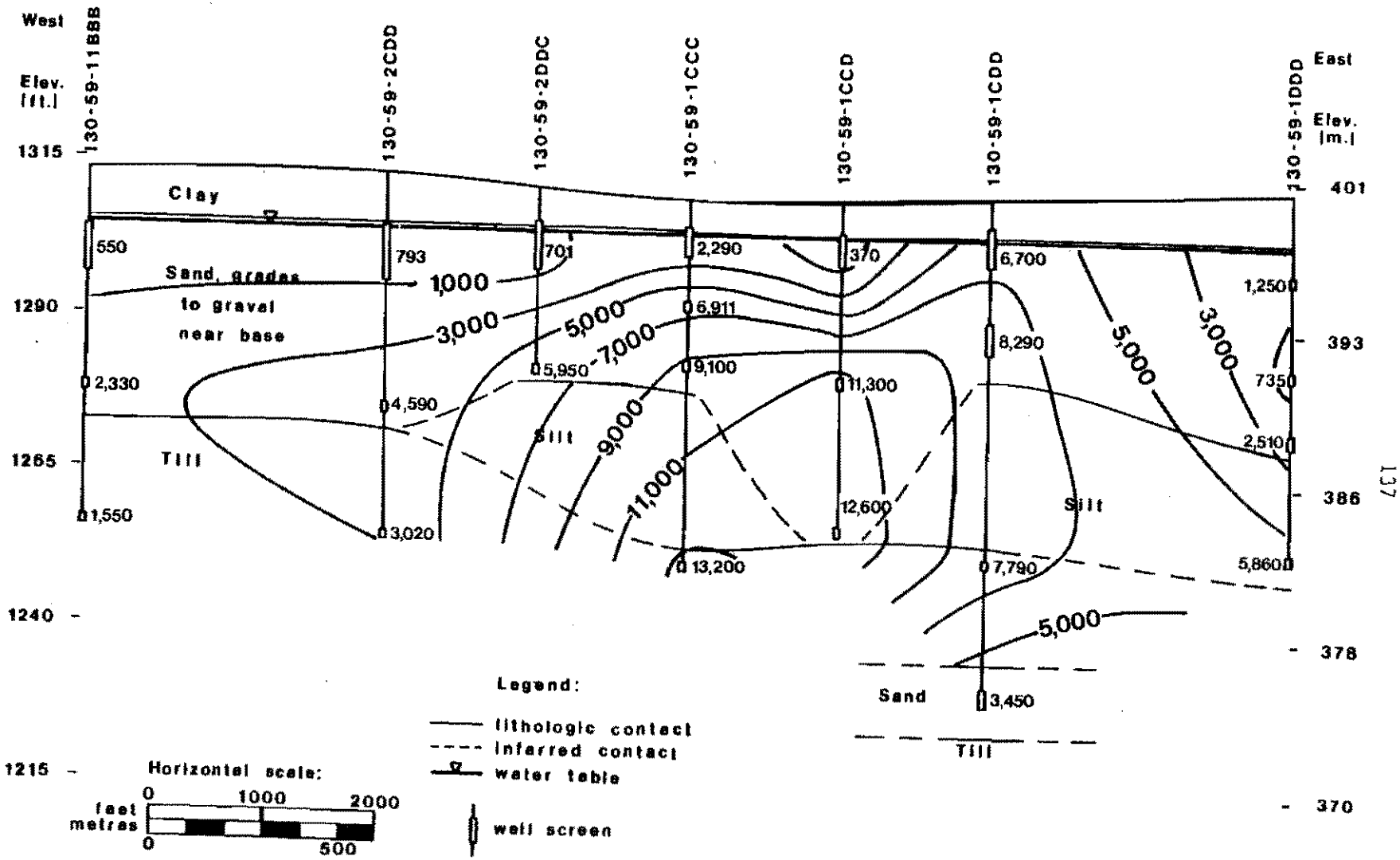
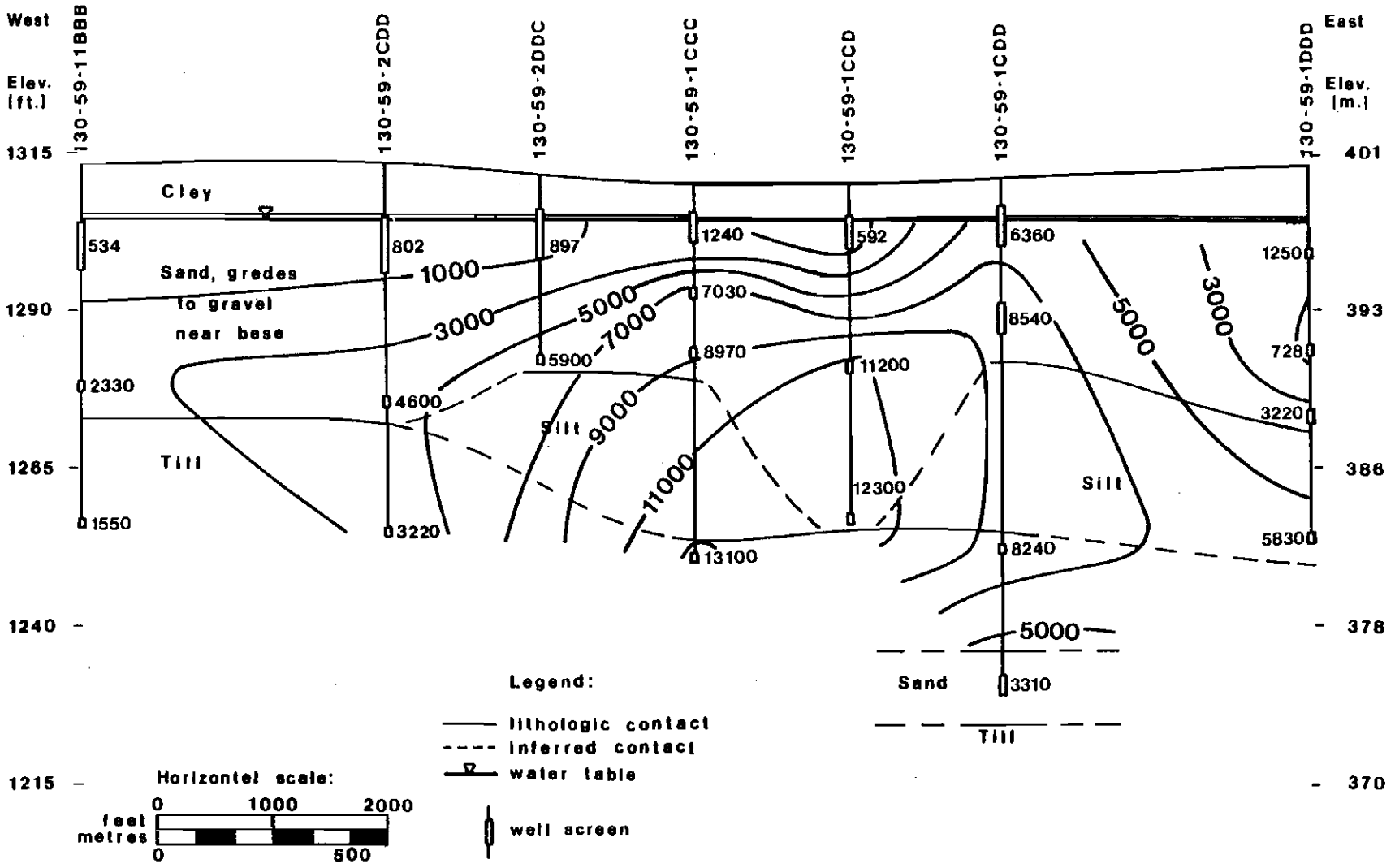

West
East
Elev. (ft.)
Elev. (m.)
1315
1290
1265
1240
1215
401
393
386
378
370
130-59-11BBB
130-59-2CDD
130-59-2DDC
130-59-1CCC
130-59-1CCD
130-59-1CDD
130-59-1DDD
Clay
Sand, grades to gravel near base
Till
Silt
Sand
550
793
701
2,290
370
6,700
1,250
2,330
4,590
5,950
6,911
9,100
11,300
8,290
7350
2,510
1,550
3,020
13,200
12,600
7,790
5,860
3,450
1,000
3,000
5,000
7,000
9,000
11,000
Legend:
lithologic contact
inferred contact
water table
well screen
Horizontal scale:
feet
metres
0
1000
2000
500

Figure 55. TDS distribution along the east-west traverse (April 19-26, 1984).


West
East
Elev. (ft.)
Elev. (m.)
130-59-11BBB
130-59-2CDD
130-59-2DDC
130-59-1CCC
130-59-1CCD
130-59-1CDD
130-59-1DDD
1315
1290
1265
1240
1215
401
393
386
378
370
Clay
Sand, gredes to gravel near base
Till
Silt
Sand
534
2330
1550
802
4600
3220
897
5900
1240
7030
8970
13100
592
11200
12300
6360
8540
8240
12500
7280
3220
58300
3310
1000
3000
5000
7000
9000
11000
5000
3000
5000
Legend:
lithologic contact
inferred contact
water table
well screen
Horizontal scale:
0 1000 2000
feet
metres
0 500

130-59-1CCC, one of the water-table wells which decreased in TDS, a loss of over 1000 mg/L from 2,290 to 1,240 mg/L occurred. At the base of the aquifer a decline of 300 mg/L was measured at 130-59-1CCD and a smaller decline at 130-59-1CCC. Increases occurred at 130-59-1CDD and 130-59-1DDD. The till/silt wells increased at 130-59-2CDD and 130-59-1CDD and a slight decline occurred at 130-59-1CCC. The lower aquifer also had a decline in TDS.

The TDS distribution along the north-south traverse generally displayed lower concentrations of dissolved solids than the east-west traverse (Figure 56). Fresh water is found at the water table except in the center of the traverse, at 130-59-2CBB, where there is brackish water. The rest of the aquifer and till units contain brackish water. The highest TDS values are at the base of the aquifer near the center of the depression.

The TDS changes along the north-south traverse are similar to those along the east-west traverse. From September to October-November, 1983 the water-table wells did not change appreciably, whereas the base of the aquifer showed increases at 130-59-2BCB, 130-59-2CCB, and 130-59-11BBB (Figures 56 and 57). The till exhibited lower TDS in October-November at 130-59-2BBB while the other till wells showed increases.

Changes in TDS from October-November, 1983 to February, 1984 were minor (Figure 58). Near the water table, a slight decrease occurred at 130-59-2CBB while the other water-table wells had no change. The base of the aquifer had an increase at 130-59-2CCB and 130-59-11BBB while a decrease occurred at 130-59-2BCB. The till wells showed no changes greater than 100 mg/L.

Figure 56. TDS distribution along the north-south traverse (September, 1983).

Figure 57. TDS distribution along the north-south traverse (October-November, 1983).

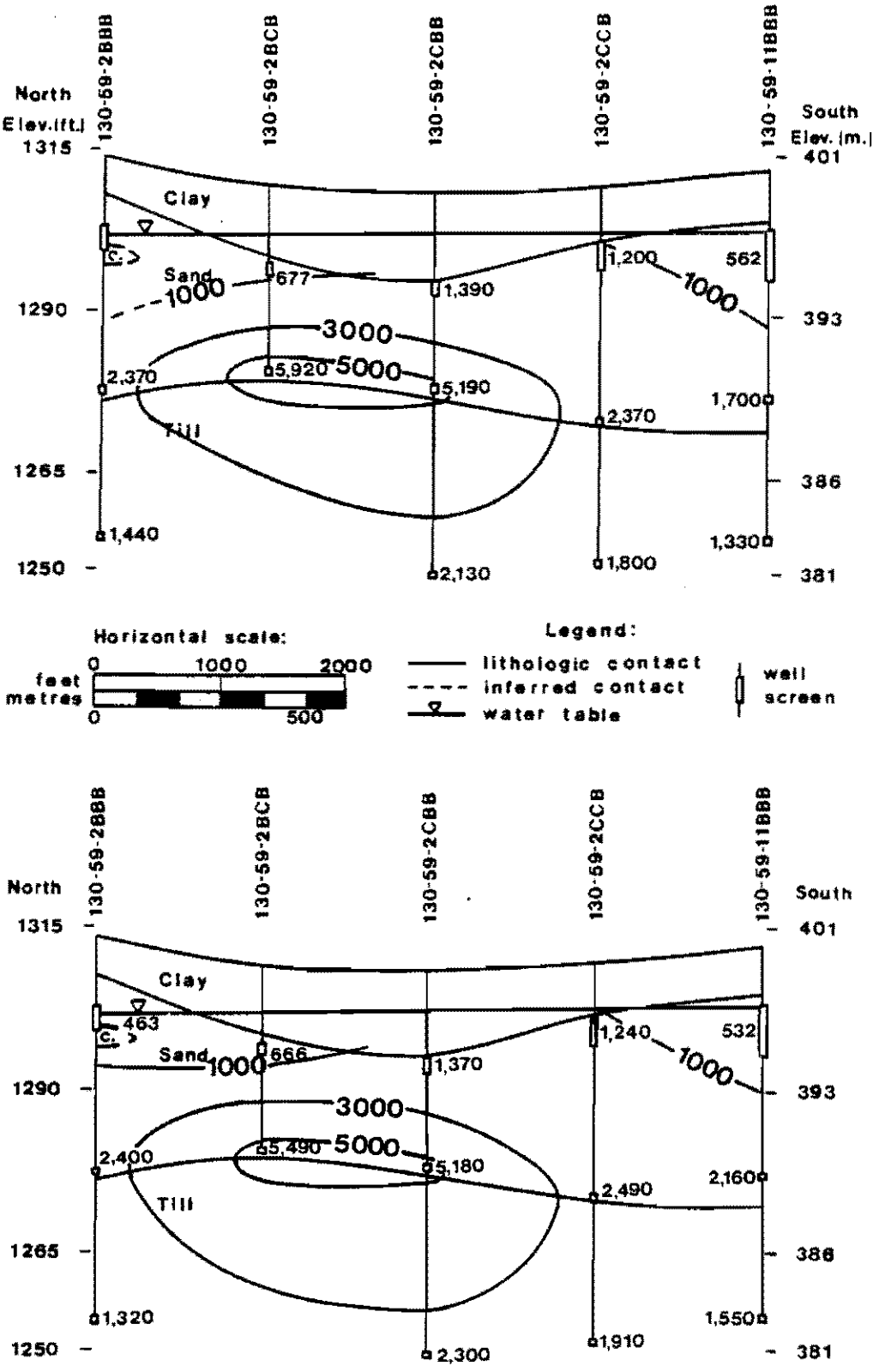
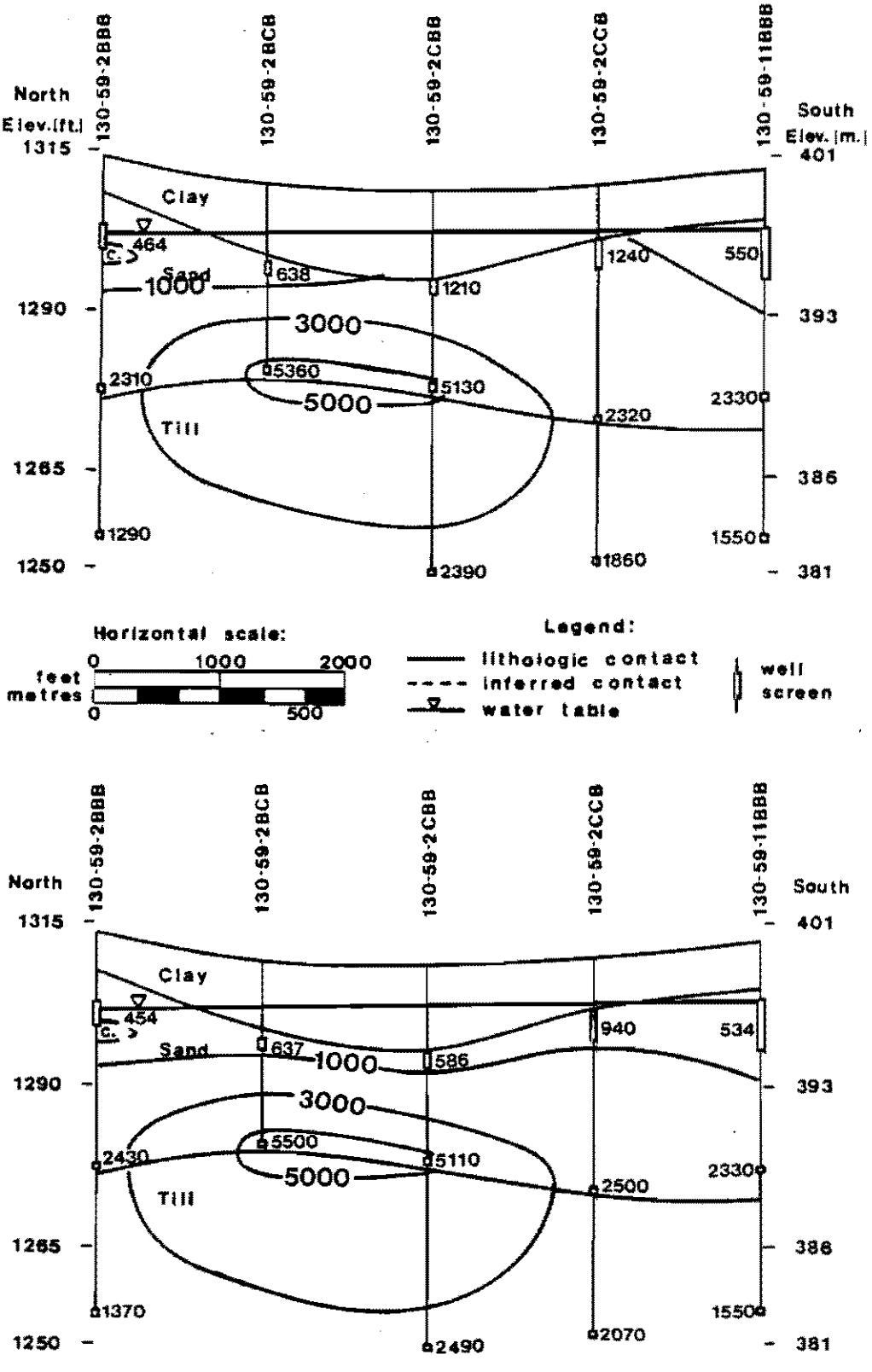

North
Elev.(ft.)
1315
1290
1265
1250
South
Elev. (m.)
401
393
386
381
130-59-2BBB
130-59-2BCB
130-59-2CBB
130-59-2CCB
130-59-11BBB
Clay
Sand
Till
1000
3000
5000
677
1,390
1,200
562
2,370
5,920
5,190
2,370
1,700
1,440
2,130
1,800
1,330
Horizontal scale:
feet
metres
0
1000
2000
500
Legend:
lithologic contact
inferred contact
water table
well screen
463
666
1,370
1,240
532
2,400
5,490
5,180
2,490
2,160
1,320
2,300
1,910
1,550

Figure 58. TDS distribution along the north-south traverse (February 18-26, 1984).

Figure 59. TDS distribution along the north-south traverse (April 19-26, 1984).


North
Elev.(ft.)
1315
1290
1265
1250
South
Elev.(m.)
401
393
386
381
130-59-2BBB
130-59-2BCB
130-59-2CBB
130-59-2CCB
130-59-11BBB
Clay
Sand
Till
1000
3000
5000
464
638
1210
1240
550
2310
5360
5130
2320
2330
1290
2390
1860
1550
Horizontal scale:
feet
metres
0
1000
2000
500
Legend:
lithologic contact
inferred contact
water table
well screen
North
Elev.(ft.)
1315
1290
1265
1250
South
Elev.(m.)
401
393
386
381
130-59-2BBB
130-59-2BCB
130-59-2CBB
130-59-2CCB
130-59-11BBB
Clay
Sand
Till
1000
3000
5000
454
637
586
940
534
2430
5500
5110
2500
2330
1370
2490
2070
1550

Variations in TDS from February to April, 1984 illustrated a major decrease in TDS along the water table at 130-59-2CBB and 130-59-2CCB (Figure 59). The base of the aquifer increased at 130-59-2BBB, 130-59-2BCB, and 130-59-2CCB. Virtually no change was recorded at the remaining aquifer wells. Increases in the till were observed at 130-59-2CBB and 130-59-2CCB, whereas the others had little change.

Evidence for Reducing Conditions in the Aquifer

Reducing conditions are quite common in aquifers after the oxygen has been depleted from the soil and near-surface waters. Above a pH of 4.8 the solubility of the ferric species of iron (Fe^{3+}) is less than 0.01 mg/L (as Fe) (Hem, 1970, p. 116). The solubility of other oxidized forms of iron are equally small. Therefore, near a pH of 7.0, concentrations of iron greater than 0.1 mg/L are most likely ferrous species (Fe^{2+}). Chemical analyses indicate concentrations up to 18 mg/L of Fe within the aquifer. This iron concentration is much greater than the 0.3 mg/L EPA standard for drinking water (Freeze and Cherry, 1979, p. 386).

Reducing conditions were also indicated by the odor of hydrogen sulfide gas (H_2S) detected while bailing the wells. The gas had a rotten egg/sulfur odor that was quite pungent in some wells. H_2S gas is produced by the reduction of the sulfate ion (Drever, 1982, p. 269) by the reaction:

$$SO_4^{2-} + 8e^- + 10H^+ = H_2S + 4H_2O.$$

The degree of reducing conditions, measured as electron activity (pe), is not known. Mineralogical evidence for low pe conditions includes the presence of siderite and pyrite within the till unit beneath the upper aquifer. Siderite ($FeCO_3$) was identified within the till by XRD analysis. Although siderite was not observed in hand samples it is abundant enough to be detected by XRD. Most siderite forms in oxygen-poor environments as a precipitate (Phillips and Griffen, 1981, p. 59). Alternatively, the presence of siderite may be explained by the glacial transport of Cretaceous bedrock from the north. The Cretaceous Pierre Formation does contain iron, but only as small localized nodules (siderite) and as pyritized fossils (Gill and Cobban, 1965). It is assumed that the surficial clay and the sands and gravel also contain pyrite and siderite, even though XRD did not detect them. Therefore, it is possible siderite precipitated within the till under low pe conditions.

The combination of iron, sulfur, and carbonate within a groundwater system can be represented on a pe-pH or Eh-pH diagram in which the stability fields for the mineral phases pyrite and siderite can be shown (Drever, 1983, p. 273). It is sufficient to say that both siderite and pyrite may precipitate at pH values commonly present in groundwater when low pe levels exist.

A small sample of pyrite was obtained from till at 130-59-2CCB at a depth of 56-60 feet (17.0-18.3 m). The sample is 0.31 inches (0.80 cm) in length, 0.094-0.063 inches (2.4-1.6mm) wide, columnar- to blade-shape, consisting of small subhedral crystals with a fractured surface at both ends implying the sample was larger and then broken. Although

pebbles within these tills appear abraded and flattened, the pyrite sample does not show any evidence of these characteristics. All of the above factors imply the pyrite sample formed in situ after the till was deposited and most likely along a fracture. If this is the case, pe conditions are, or were, low enough for the reduction of sulfate and precipitation of pyrite.

Mineral Saturation Within the Aquifer

Saturation indices of selected minerals, as computed by the WATEQM-SE program, were plotted on cross-sections of the two traverses (Appendix G). Because the indices were reported as log values, saturation values are equal to zero, oversaturation values are positive, and undersaturation values are negative.

The WATEQM-SE program was very sensitive to pH variations. During the February sampling period, pH was noted to be much lower than previously measured. In one instance a value of 5.4 was measured, whereas three months previously the pH value was 6.7. After returning from the field it was determined that either the standardizing solution or the pH meter were in error. The resultant WATEQM-SE output with the February data produced undersaturation with almost all mineral species. To compensate for the pH error the February lab pH value was subtracted from the October-November lab pH and the resulting difference was subtracted from the October-November field pH to obtain an adjusted February field pH. The adjusted February field pH was then used in the WATEQM-SE program. The adjusted pH values may not be accurate, but they are assumed to be closer to the true values than the field pH values.

The zones of saturation for calcite, dolomite, and siderite indicate similar changes throughout the study period. The area of saturation for the carbonate minerals is assumed to vary due to precipitation and dissolution of minerals and changes in pH. Because of the sensitive nature of the WATEQM-SE program, inaccurate pH measurements may have had a greater effect on the carbonate-saturated zone distribution than mineral phase changes. Along the east-west traverse from the September, 1983 through the April, 1984 sampling periods the carbonate-saturated zones were consistently near the base of the aquifer, near the center of the traverse, and within the upper part of the till/silt units.

Gypsum saturation is not affected by pH changes and showed a stable distribution along the east-west traverse during the study period. Gypsum saturation was centered over the groundwater sink at 130-59-1CCD and along the top portion of the till unit on the eastern part of the traverse.

Saturation with respect to carbonate minerals along the north-south traverse primarily occurred at the aquifer/till interface and near the extreme ends of the traverse.

Gypsum saturation was not present along the north-south traverse. Nearly saturated conditions occur along the base of the aquifer at the northern wells over the study period.

Possible Evaporation Indicators

Individual chemical constituents were examined after each of the water analyses were received. One observed trend was that the magnesium

ion (Mg^{2+}) generally increased in concentration toward the center of the east-west traverse. The calcium ion (Ca^{2+}) concentration also increased, but the change was not as great as for magnesium. A possible explanation for these relative changes is that the Ca^{2+}/Mg^{2+} ratio may be an indication of an evaporative mechanism which concentrates dissolved solids (Robert Shaver, verbal communication, 1984). Previous hydrogeochemical studies in North Dakota focused on areas where Ca^{2+} and Na^{+} were the predominant cations in solution (Gerald Groenewold, verbal communication, 1984).

Magnesium carbonate is more soluble than calcium carbonate and magnesium sulfate is more soluble than calcium sulfate. It is likely, that in an evaporative setting, magnesium ions will remain in solution while calcium ions may be removed by precipitation.

Ca^{2+}/Mg^{2+} ratios, in meq, for February and April were plotted for the east-west and north-south traverses (Figures 60-63, respectively). The lowest Ca^{2+}/Mg^{2+} ratios were located within the traverses where the highest values of TDS occurred. The February TDS values and Ca^{2+}/Mg^{2+} ratios were analyzed using linear regression to determine if any correlation existed between the two. The results of the analysis indicate a definite inverse correlation in the till between the Ca^{2+}/Mg^{2+} ratio and TDS ($r = -0.97$) (Table 4). The wells at the base of the aquifer and water-table wells of the NDSWC do not have as strong a correlation as the till wells. The same inverse correlation is obtained from USBR wells within the trough and to a lesser extent outside the trough.

Figure 60. Calcium/magnesium ratios along the east-west traverse (February, 1984).

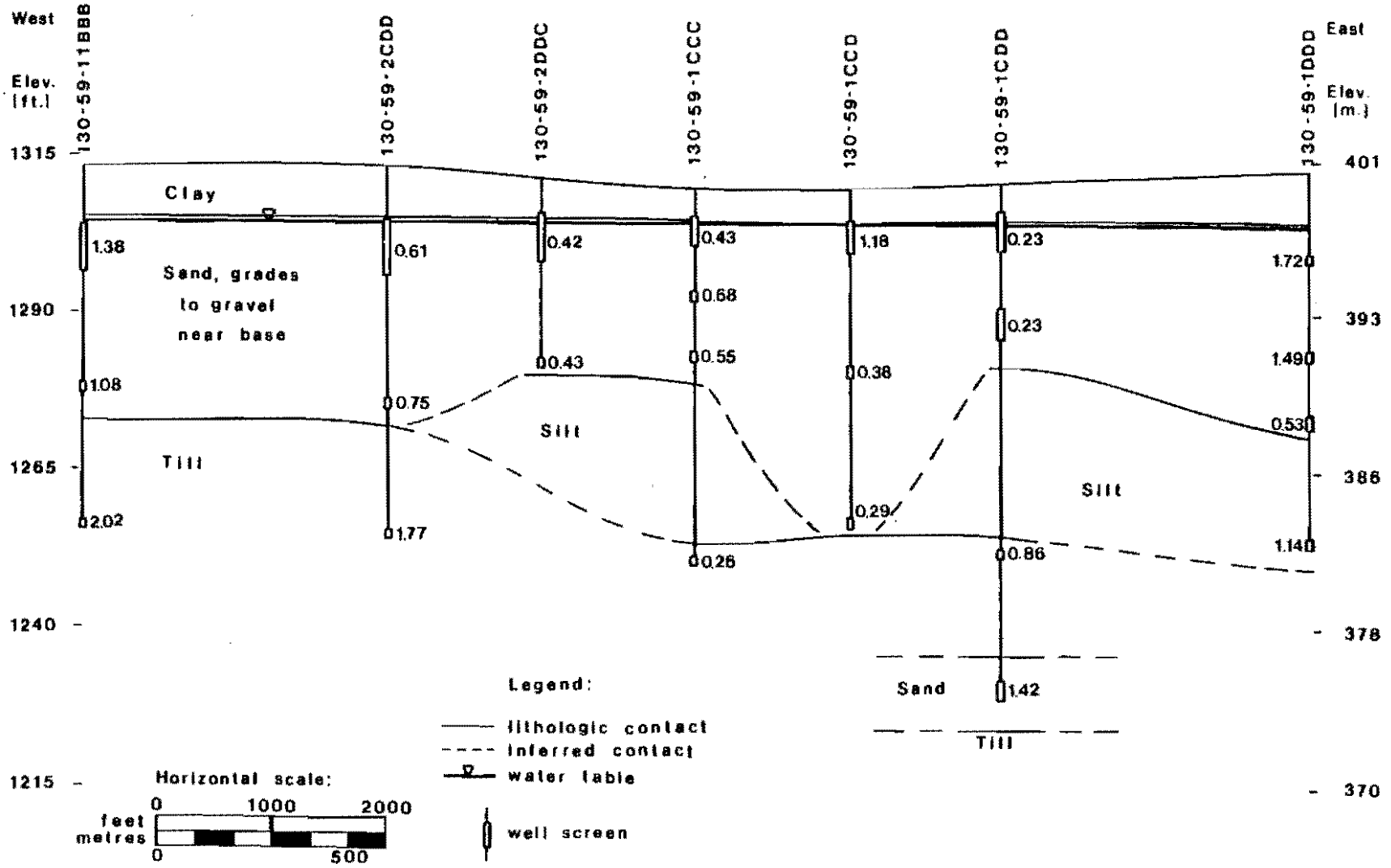

West
East
Elev. (ft.)
Elev. (m.)
130-59-11BBB
130-59-2CDD
130-59-2DDC
130-59-1CCC
130-59-1CCD
130-59-1CDD
130-59-1DDD
1315
1290
1265
1240
1215
401
393
386
378
370
Clay
Sand, grades to gravel near base
Till
Silt
Silt
Sand
Till
1.38
1.08
2.02
0.61
0.75
1.77
0.42
0.43
0.43
0.55
0.68
0.26
1.18
0.38
0.29
0.23
0.23
0.86
1.42
1.720
1.490
0.530
1.140
Legend:
lithologic contact
inferred contact
water table
well screen
Horizontal scale:
feet
metres
0
1000
2000
0
500

Figure 61. Calcium/magnesium ratios along the east-west traverse (April, 1984).

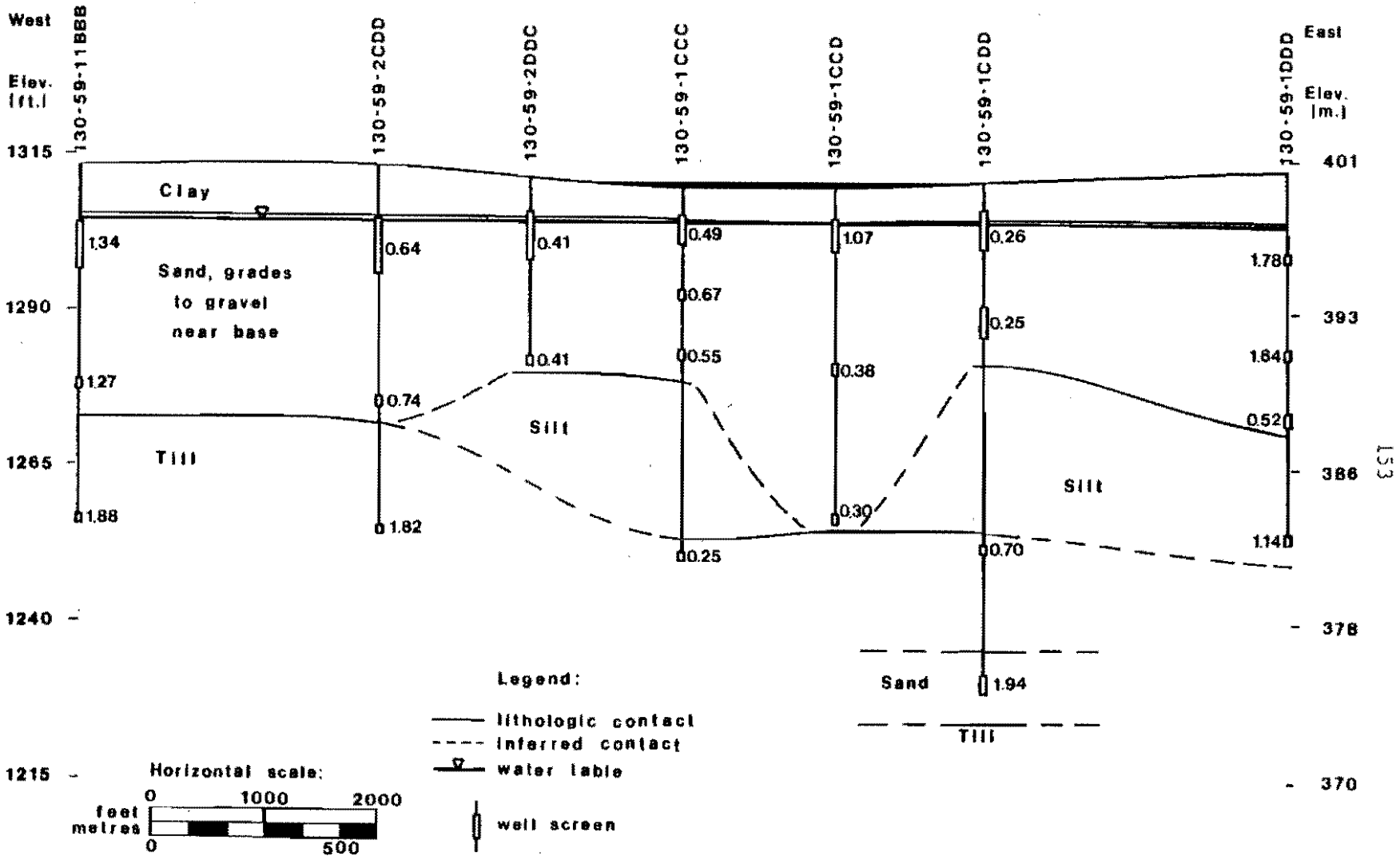
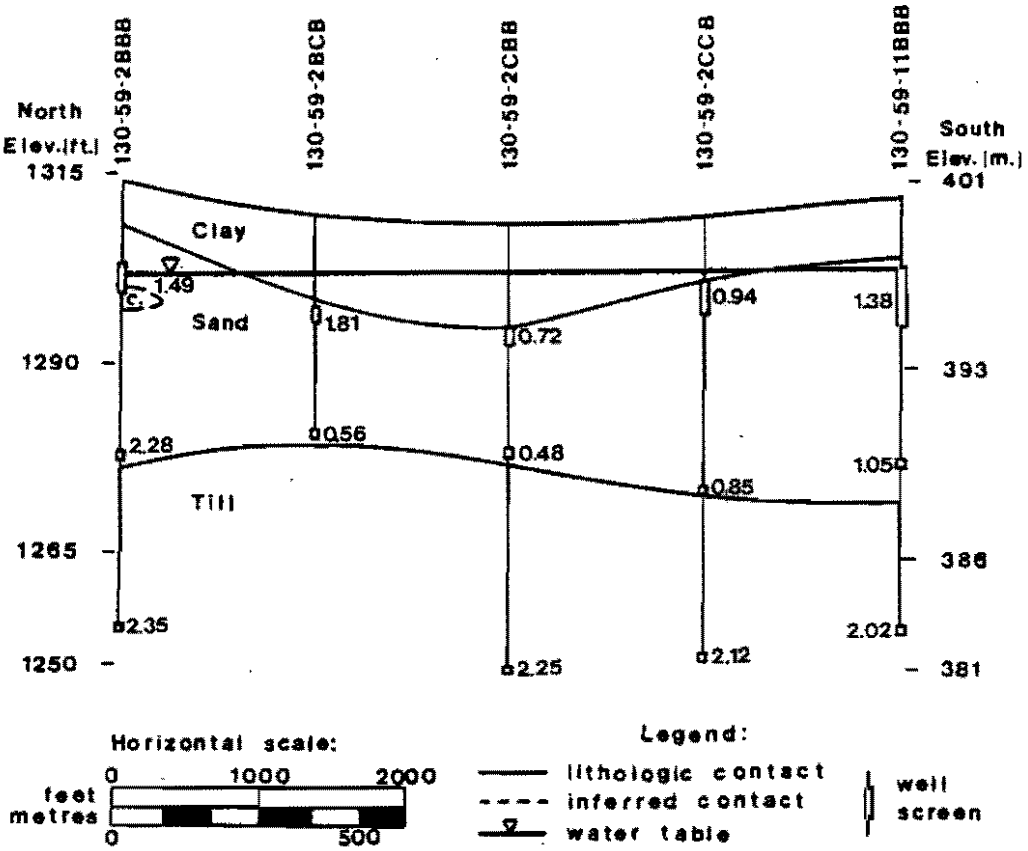

West
East
Elev. (ft.)
Elev. (m.)
130-59-11BBB
130-59-2CDD
130-59-2DDC
130-59-1CCC
130-59-1CCD
130-59-1CDD
130-59-1DDD
1315
1290
1265
1240
1215
401
393
386
378
370
Clay
Sand, grades to gravel near base
Till
Silt
Silt
Sand
Till
1.34
0.64
0.41
0.49
1.07
0.26
1.78
0.67
0.25
1.27
0.41
0.55
0.38
1.64
0.74
0.52
1.88
1.82
0.30
0.25
0.70
1.14
1.94
Legend:
lithologic contact
inferred contact
water table
well screen
Horizontal scale:
feet
metres
0
1000
2000
0
500

Figure 62. Calcium/magnesium ratios along the north-south traverse (February, 1984).

Figure 63. Calcium/magnesium ratios along the north-south traverse (April, 1984).


North
Elev.(ft.)
1315
1290
1265
1250
130-59-2BBB
130-59-2BCB
130-59-2CBB
130-59-2CCB
130-59-11BBB
South
Elev.(m.)
401
393
386
381
Clay
Sand
Till
1.49
1.81
0.72
0.94
1.38
2.28
0.56
0.48
0.85
1.05
2.35
2.25
2.12
2.02
Horizontal scale:
feet
metres
0
1000
2000
500
Legend:
lithologic contact
inferred contact
water table
well screen

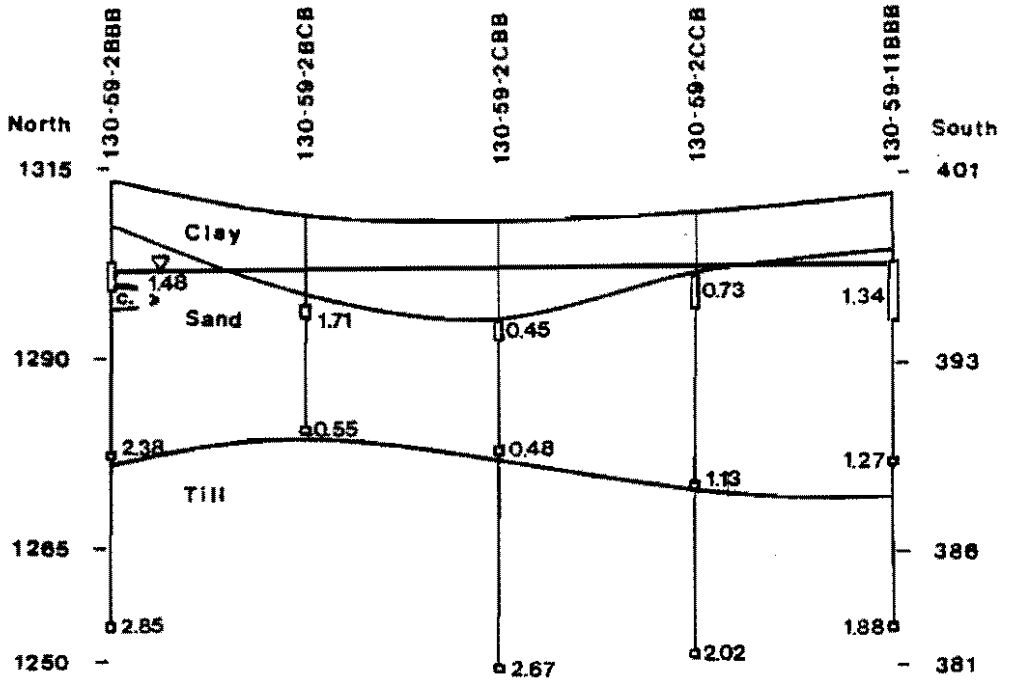

North
1315
1290
1265
1250
130-59-2BBB
130-59-2BCB
130-59-2CBB
130-59-2CCB
130-59-11BBB
South
401
393
386
381
Clay
Sand
Till
1.48
1.71
0.45
0.73
1.34
2.38
0.55
0.48
1.13
1.27
2.85
2.67
2.02
1.88

Table 4

Statistical Results for

Calcium/Magnesium Ratios versus TDS

Well	Unit	No. of samples	Ave. TDS (mg/L)	Ave. Ca/Mg	Std. Dev. TDS (mg/L)	Std. Dev. Ca/Mg	Corr. coef.
NDSWC	Till	8	4620.	1.60	4160.	0.76	-0.97
NDSWC	Base of aquifer	11	5500.	0.73	3340.	0.57	-0.58
NDSWC	Water Table	12	1930.	0.97	2340.	0.54	-0.55
USBR	Inside trough	7	2700.	0.73	1900.	0.46	-0.65
USBR	Outside trough	20	470.	1.84	116.	0.35	-0.45

Sodium-chloride concentrations have been used to indicate evaporative conditions within lakes (Eugster and Hardie, 1978 and Eugster and Jones, 1979). Information regarding evaporative lakes may be applied, with some assumptions, to shallow aquifers. In the discussion of this mechanism it is assumed that: (1) sodium and chloride will not react with other chemical constituents; and (2) no new source of either sodium or chloride is present.

Concentrations of Na^+ and Cl^- were plotted using February, 1984 water analyses from USBR and NDSWC wells (Figure 64). It is assumed that the initial concentrations of sodium and chloride were low. If simple evaporation were to occur the concentrations would then parallel a 45^o slope. It is obvious that the points fall above the evaporative concentration line. If simple evaporation does occur it does so in conjunction with other geochemical processes such as ion exchange.

Concentrations of Mg^{2+} and Cl^- were plotted using the February, 1984 water analyses from the NDSWC wells (Figure 65). The concentrations were plotted by individual nests using the water-table well and the base of the aquifer well. A short line was drawn between the two wells of each nest. The long solid line represents the expected results of simple evaporation. The slope of the nested-well values is roughly parallel to the evaporative concentration line. This implies that the dissolved constituents concentrated by evaporation.

Figure 64. Logarithmic concentrations of sodium and chloride (February, 1984). The dashed line represents the 45° slope expected from simple evaporation.

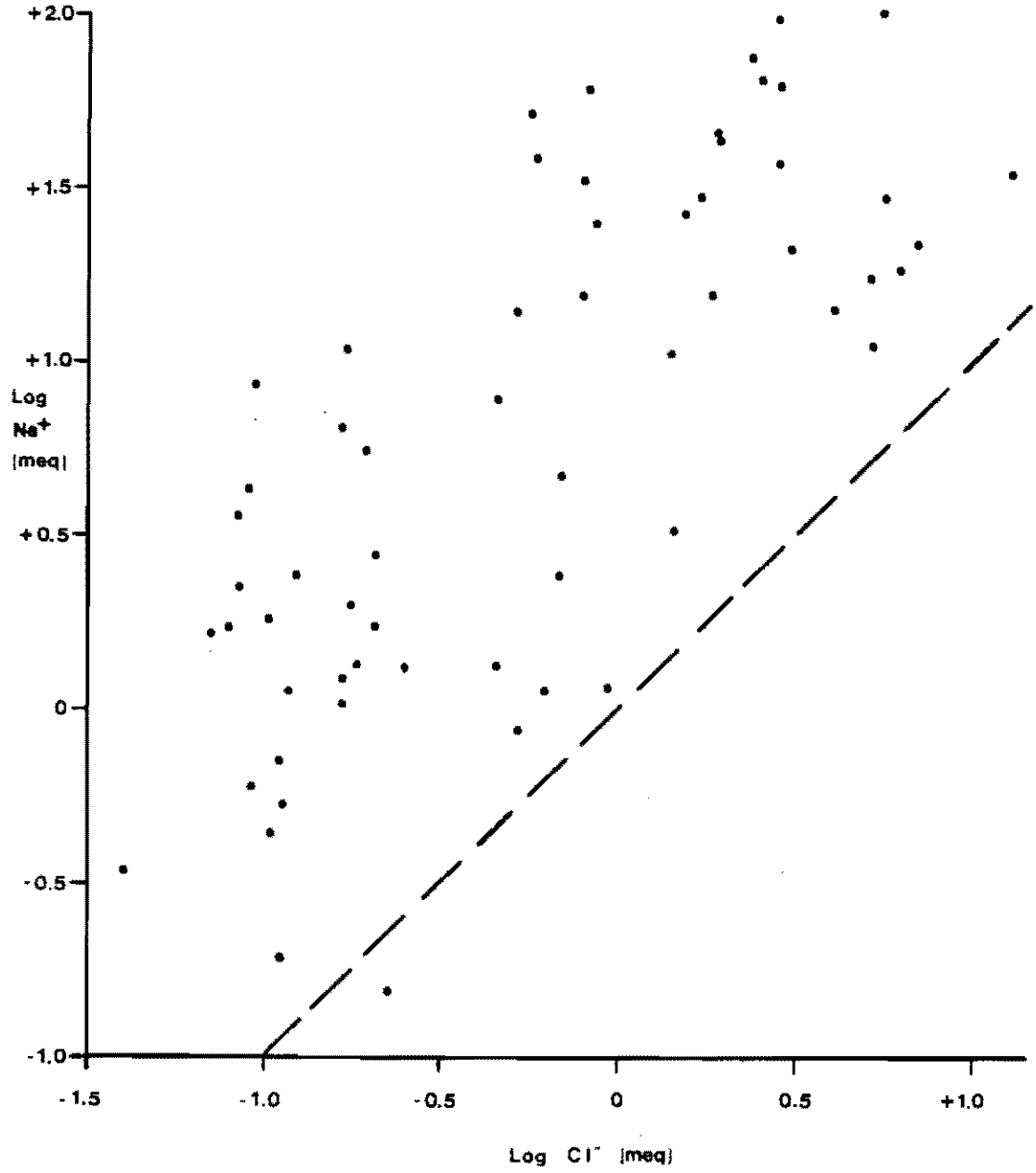
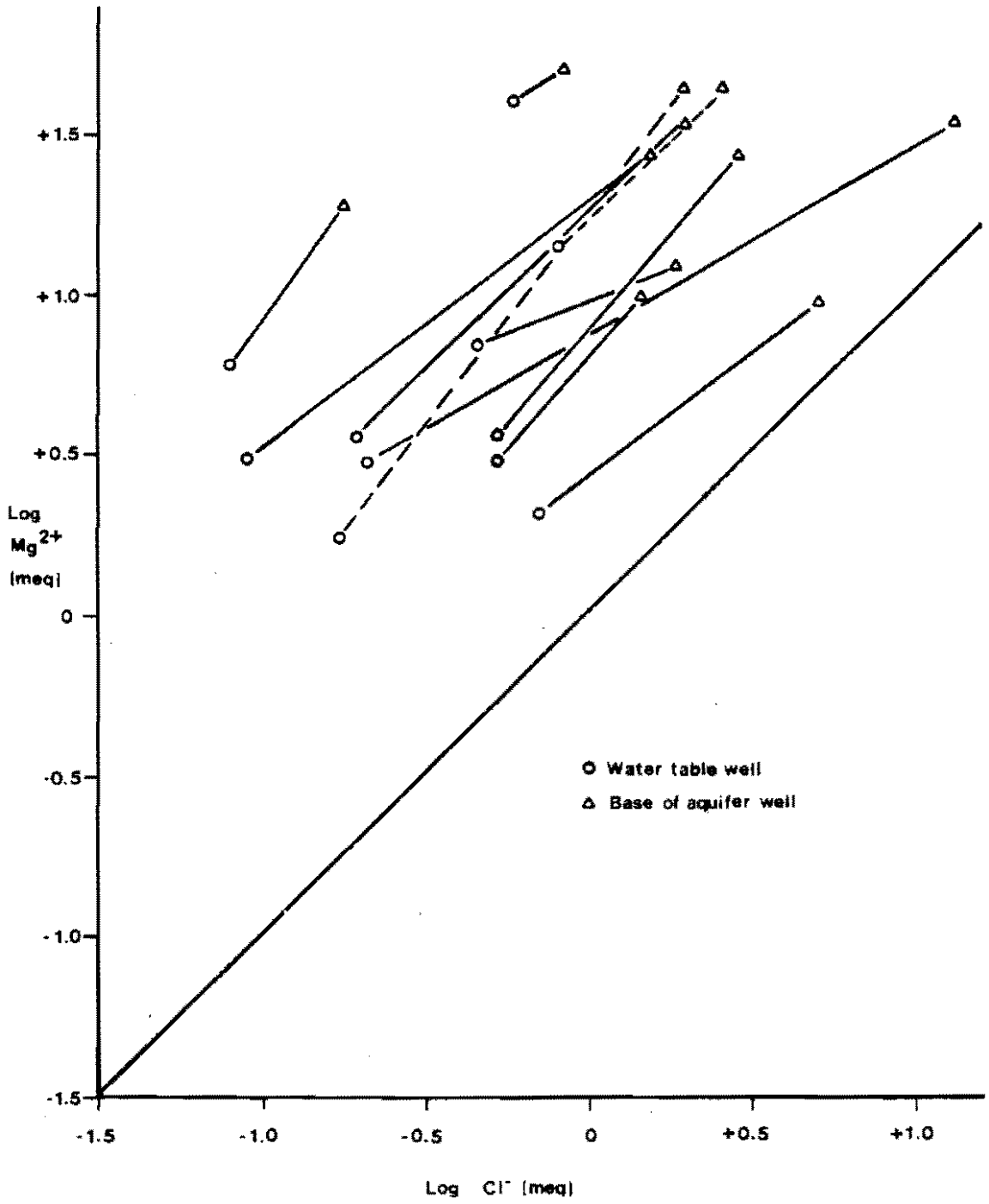

+2.0
+1.5
+1.0
Log
Na+
(meq)
+0.5
0
-0.5
-1.0
-1.5
-1.0
-0.5
0
0.5
+1.0
Log Cl⁻ (meq)

Figure 65. Logarithmic concentrations of magnesium and chloride from February, 1984 water analyses along the two traverses. The small lines connect nested water-table wells and the base of the aquifer wells for a single location. The long solid line represents the 45° slope expected from simple evaporation.


+1.5
+1.0
+0.5
Log
Mg^{2+}
(meq)
0
-0.5
-1.0
-1.5
-1.5
-1.0
-0.5
0
+0.5
+1.0
Log Cl^- (meq)
Water table well
Base of aquifer well

DISCUSSION

As is the case in any groundwater system the groundwater chemistry is inextricably linked to the groundwater flow patterns and, in turn, solid/fluid reactions. The relationship between groundwater chemistry and flow patterns at the study site will be explained in the following sections.

Groundwater Flow

Upward gradients in the unsaturated zone during the summer months indicate that the topographic depression is the site of groundwater discharge in that season (Table 2). Most infiltrating water during the summer is prevented from recharging the groundwater flow system (Rehm, et al., 1982, p. 18). An example of this is the thunderstorm that dropped 2.9 inches (7.4 cm) of rain on August 16, 1983. The 36-inch tensiometer barely deflected and the 60-inch tensiometer did not change at all. Apparently the precipitation is held in the unsaturated zone and is discharged by evapotranspiration.

The spring tensiometric data indicate a period of recharge because of consistently higher hydraulic heads at the 36-inch tensiometer (Table 3). Precipitation events during this time created an increase in soil moisture to which both tensiometers reacted with the 36-inch tensiometer responding first.

Winter is the most stable time of the year for shallow water table systems because major recharge or discharge events do not occur. Stable flow along the east-west traverse can best be represented on February 2, 1984 (Figure 30) where lateral flow occurred from the east and the west toward the groundwater sink. Upward flow also occurred from the lower aquifer. Under these conditions, horizontal groundwater flow from topographic highs toward topographic lows would be expected (Toth, 1963). The non-sloping topographic high positions typically represent recharge sites and the topographic lows typically constitute discharge sites. Discharge during the winter would occur by groundwater flow along the axis of the depression, as indicated by the sink, and possibly by the formation of frost. Frost formation can decrease water levels within shallow aquifers during the winter (Rehm, et al., 1982, pp. 20-21). Frost was observed in the upper portion of the well casings and was likely to have formed in the unsaturated zone. A general drop in water levels occurred during the winter months (Figures 29-32).

The winter snows and the spring rains made a considerable amount of water available for recharge. Within the depression, where the water table is closest to the surface, recharge occurred very quickly, creating a groundwater mound. Continued snow melt and precipitation ponded excess water on the surface after the water table rose to ground

level. An event of this type is called depression-focused recharge (Meyboom, 1966).

The groundwater mound, in the center of the depression, dissipated by outward flow from the groundwater high. Evapotranspiration, although not a large factor in the months of March and April (Rehm, et al., 1982, p. 59), may have contributed to the dissipation of the groundwater mound in May and June. It is assumed that later in the summer hydraulic head values would have decreased in the center of the east-west traverse thereby allowing groundwater flow to return toward the center of the traverse.

The movement of water after a major recharge event can be complex. A possible scenario for the July, 1983 recharge event can be reconstructed along the east-west traverse. A depression-focused recharge event formed with outward flow (from east to west). It is assumed that evapotranspiration contributed in lowering the hydraulic heads across the entire depression. The water table, being so close to the surface, facilitated water loss in the depression. After hydraulic heads decreased in the depression, the area to the west, outside the depression, had higher hydraulic heads creating a flow reversal from west to east. The hydraulic head data for August and September support this (Figures 26 and 27). Through the fall the gradients increased toward the sink until groundwater, along the eastern portion of the traverse, flowed back toward the sink and stable flow formed. These flow characteristics are analogous to water, dumped into a tub, sloshing back and forth, with each subsequent reversal having lower gradients until it stabilizes. The recharge event would be considered to be the

reversal of normal flow and the changes that follow would be the resumption of normal (stable) conditions.

The north-south traverse exhibited a similar response to recharge events (Figures 44-47). Prior to the spring recharge event a south-to-north flow was located along the traverse. During the recharge event a groundwater mound also formed along the central axis of the depression. On June 4, 1984 the mound had nearly dissipated and normal flow had started to resume.

Recharge events can disturb flow between aquifers. Recharge is indicated by gradient reversals as illustrated on figures 33-36. The higher hydraulic heads within the upper aquifer in the spring of 1984 imply movement of water through the intervening till into the lower aquifer. This movement of water is recharging the lower aquifer. It can be argued, though, that recharge may be from some other source or location. However, the till is only 25 feet (7.6 m) thick at 130-59-1CDD and may conduct large volumes of water as implied by the measured high hydraulic conductivities. Stable flow with an upward gradient between the aquifers is indicated before the spring recharge of 1984 and just afterwards (Figures 32 and 36). This upward gradient implies discharge from the lower into the upper aquifer. Previous studies also indicate movement between the Oakes aquifer and the Spiritwood aquifer (Armstrong, 1980 and 1982).

One part of the groundwater flow regime was apparently stable throughout the study period. The hydraulic head values in the sink of the east-west traverse were always greater than those in the sink of the north-south traverse. This implies a constant movement of water toward

the James River along the axis of the depression. Because the gradients along the axis of the depression are not very large, movement of groundwater is slow.

In summary, major recharge events can disrupt flow patterns. The results from the study area imply major recharge events occurred in July, 1983 and during the spring of 1984. The July, 1983 event exhibited flow which prevented stable flow characteristics from re-establishing until the winter of 1983-84. The flow characteristics imply reversals of vertical and horizontal movements in which water is constantly moving but at a very slow rate.

Groundwater Chemistry

Evapotranspiration has been suggested as the main mechanism of groundwater discharge from the depression. Evaporation can also increase the concentrations of dissolved solids in solution (Al-Droubi, et al., 1980). When saturation of a mineral species occurs the mineral may precipitate.

Evaporation of groundwater occurs rapidly where the water table is closest to the surface (Rehm, et al., 1982). The most probable location for precipitated minerals is, therefore, in the center of the depression. Precipitated minerals are usually located on the surface, just below the surface, or in the capillary fringe above the water table

(Drever, 1982, pp. 208-209). The exact position of precipitation is dependent upon the initial concentration of the water and the location of the water table.

Evidence for such precipitation is found in the surficial clay where calcite and gypsum are indicated by lithologic logs, XRD analysis, and saturation data from the WATEGM-SE program. Individual gypsum crystals, up to 1 inch (2.54 cm) in diameter, were observed. These crystals were in the unsaturated zone at 130-58-17BBB and are assumed to have precipitated in the capillary fringe of the water table. Calcite, however, was concentrated in the C horizon of the soil and most likely precipitated from dissolved carbonate minerals from above. In the center of the depression, calcite may have precipitated close to the surface in the same manner described above for gypsum. Gypsum also precipitated along the base of the aquifer within the silts and tills as indicated by the presence of gypsum nodules.

The source of the precipitated calcite is most likely the dissolution of carbonates within the aquifer. Gypsum, on the other hand, has two possible sources: (1) gypsum from the Cretaceous bedrock, via glacial incorporation and deposition; and (2) pyrite oxidation producing sulfate ions and carbonate dissolution contributing calcium ions.

Rainfall from most rainstorms will not completely dissolve the precipitated minerals in the summer (Drever and Smith, 1978). Only major recharge events will penetrate the unsaturated zone, dissolve the soluble minerals, and contribute to the groundwater system. The precipitated minerals will dissolve in order of solubility. For example, gypsum will dissolve before calcite.

The solution with the newly dissolved constituents will flow downward through the unsaturated zone under the influence of gravity. Upon reaching the water table the new solution will either have a higher TDS, a lower TDS or the same concentration as the solution in the aquifer. The new solution will, of course, flow in response to hydraulic gradients. However, the density difference between the new solution and the groundwater will dictate if the new solution will sink by its greater density (miscible displacement). Miscible displacement has been suggested as a mechanism for the descent of higher concentrated solutions in aquifers (Nield, 1968 and Bear, 1972, pp. 659-660). It is important to note that the usual major recharge event is the spring snow melt. The melted snow is probably close to the maximum density of water, approximately 4° C. Combined with higher TDS, a cold density flow through the interstices would most likely leave fresher water on the surface of the aquifer.

The downward movement of denser, higher TDS water is analogous to the fall turnover which occurs in temperate lakes. Density differences, either by temperature or salinity, can initiate convection currents in lakes (Ruttner, 1968, pp. 34-43). An increase of salt content in water of 1,000 mg/L is 100 times the density difference caused by a change in temperature from 5° to 4° (Ruttner, 1968, p. 40). It is assumed that if water can descend in a lake with only slight temperature differences, then a saline solution can be expected to move downward through fresher water in an aquifer by convection currents (miscible displacement).

Experiments performed in sand in a no-flow situation illustrate miscible displacement (Slichter, 1905). These experiments were

accomplished using a vertical tank filled with saturated sand that was subjected to charge of salt water. Over a period of 8 hours the salt water was observed to have dropped 3 feet (0.9 m) through the saturated sand. The density of the salt solution and the hydraulic conductivity of the sand was not reported. If saline water can move through sand rapidly by miscible displacement it is likely that the initial spring recharge event could have carried a denser solution to the base of the aquifer between the two sampling periods.

Previous studies of soil leaching experiments indicate that sodium, chloride, and sulfate are leached rapidly (Drever and Smith, 1978). Potassium is leached, but less rapidly. The species that are leached very slowly are calcium, magnesium, carbonate, and silica.

The dissolution of minerals within the unsaturated zone can cause a change in chemistry at the water table. The following discussion refers to chemical changes that occurred in five water-table wells during the 1984 spring recharge event. The geologic setting for each well is slightly different but similar hydrogeologic mechanisms are assumed to have occurred. These mechanisms are infiltration, initial dissolution of the more soluble minerals and removal by miscible displacement upon reaching the water table, continued infiltration and subsequent leaching of the less soluble minerals, and cation exchange. The sampling of the five water-table wells occurred at different times. The water may, therefore, have been going through any one of the above mechanisms at the time of sampling. Figure 50 indicates chemical changes in five water-table wells. The initial chemcial compositions from the five wells are varied and will be considered in terms of the direction in

which the water chemistry has changed. Water chemistry from three of these wells changed toward a calcium-magnesium bicarbonate type from a sodium sulfate type of groundwater. TDS concentrations for these wells decreased, ranging from 300-1,490 mg/L. This can be explained by the leaching and removal of sodium and sulfate species followed by downward movement of density currents or flow. Later infiltration dissolved the less soluble species of calcium, magnesium, and carbonate creating a calcium-magnesium bicarbonate-type water.

The water of one well changed toward a sodium bicarbonate-type water and decreased 1,050 mg/L, TDS. This can be explained by the removal of the initial leachate, continued leaching of the less soluble calcium and carbonate species creating a calcium bicarbonate-type water. Cation exchange with Na-montmorillonite produced a sodium bicarbonate-type water. This well is screened from 5-11 feet and is in contact with the surficial clays.

The last well increased by 1,720 mg/L, TDS and changed to a more sodium sulfate-type water. It can be assumed that gypsum had precipitated the previous summer in the surficial clay. The spring recharge dissolved some of the gypsum and cation exchange with Na-montmorillonite withdrew calcium from solution and added sodium. This process produced the observed sodium sulfate-type water. The water, with its higher TDS, would be expected to move downward into the aquifer because of its greater density. It is assumed that the surficial clay thickness is greater at this location than the other locations thereby delaying the saline recharge until the sampling date.

Groundwater flow patterns from the spring recharge can account for numerous changes in TDS along the two traverses. The groundwater mound in the center of the east-west traverse created higher hydraulic heads, which induced groundwater flow downward and outward from the center. Lower TDS values were located in the center of the traverse at most locations. It is assumed that miscible displacement had already occurred and the slower downward flow of groundwater carried slightly fresher water from above.

Two locations had significant increases in TDS along the base of the aquifer during spring recharge: 130-59-1CDD increased 250 mg/L and 130-59-1DDD increased 710 mg/L. The increases may be due to downward movement of leachate, horizontal movement from areas of higher TDS, or a combination of the two. The major increase of TDS within the till, at 130-59-1CDD, is likely due to the downward movement of water with higher concentrations of TDS from above. The lower aquifer does not, however, exhibit an increase in TDS but rather a decrease of 140 mg/L. Possible explanations for the decrease may be: precipitation of dissolved constituents or dilution resulting from the inflow of fresher water from adjacent materials.

The changes in TDS, along the north-south traverse, generally include increases at the base of the aquifer and within the tills. Decreases are located near the water table. The probable causes for these changes were the same as those for the east-west traverse: influx of freshwater at the water table; leaching of precipitated minerals and associated downward movement; horizontal movement of higher concentrations of TDS; and downward movement of higher concentrations of TDS through the till.

Major recharge events are characterized by reversals of stable flow directions. Along the east-west traverse stable flow is toward the center of the depression where the sink is located. Conversely, major recharge events exhibit outward flow. If it is assumed that outward flow will carry higher TDS water away from the center of the depression, then the return of stable flow will reconcentrate the dissolved solids in the center. Based on calculated gradients and hydraulic conductivities, flow would be on the order of several tens of feet per year.

TDS concentrations along the axis of the depression generally decrease toward the James River. The mechanisms previously mentioned appear to be operating at all points along the depression and contribute to the geochemical characteristics of the groundwater system. The highest known TDS concentration is along the east-west traverse where the groundwater sink is located. It is assumed that groundwater movement carries the highly concentrated water along the axis of the depression toward the James River. It should be noted that the sink along the north-south traverse is slightly north of the highest TDS values (Figures 43 and 58). The high TDS values along the north-south traverse are most likely produced by the operating mechanisms at the center of the traverse. The south-to-north flow appears to have pushed the concentrated water to the north. To verify this, additional piezometers should be emplaced north of the sink at 130-59-2BBB.

Evaporation has been suggested as the mechanism that concentrates the dissolved solids. Sodium/chloride ratios can be used to identify simple evaporative situations (Eugster and Hardie, 1978). Chloride is

used because it is a nonreactive ion and does not enter into any ionic exchanges. Sodium, however, does undergo cation exchange. It is logical that if a solution containing chloride undergoes evaporation and concentrates, the natural sodium and exchanged sodium in solution will also increase. Logrithmic concentrations of sodium and chloride (Figure 64) shows higher values of sodium than chloride and may represent an evaporative situation and sodium exchange during concentration.

Calcium/magnesium ratios have also been used as indicators of evaporative conditions. Calcium can be preferentially absorbed on Na-montmorillonite clay, releasing sodium, leading to decreases in the calcium/magnesium ratios. Statistical analyses (Table 4) determined an inverse correlation between the calcium/magnesium ratios and TDS within the till. Within the aquifer, the correlation between these two is not as strong.

Groundwater flow characteristics along the east-west traverse imply that the groundwater moves back and forth in the aquifer over short distances. The water, in a general sense, is fairly stationary. If groundwater with ionic constituents concentrated at the surface by evaporation moves downward by density flow it should have a composition that represents simple evaporation at a single site. It is assumed that if the horizontal movement of groundwater is minimal and vertical movement by miscible displacement occurs once or twice a year, then the vertical distribution of chemical constituents should have similar ratios indicative of evaporation at different depths.

Magnesium and chloride are believed to be conservative constituents (Eugster and Jones, 1979). The concentration of chloride is thought to

be derived almost totally from rain and snow, but may partially be derived from igneous rocks or from marine sediments incorporated in the till and from the underlying Cretaceous marine sediments. Chloride concentrations from atmospheric precipitation are quite variable but inland precipitation contributes 0.22 mg/L/year (Hem, 1970, p. 50). Even with lower chloride concentrations, atmospheric precipitation may have contributed a significant amount of chloride to the relatively stagnant flow system since the retreat of the Wisconsinan glacier. Magnesium is most likely derived from dolomite dissolution. An influx of precipitation in the system should dissolve carbonate minerals. Because calcium has a greater affinity for cation exchange than magnesium, magnesium will remain in the groundwater system.

Interpretation of the logarithmic concentrations of magnesium/chloride (Figure 65) supports the hypothesis that evaporation is the mechanism for concentrating the saline water. Individual sites of nested piezometers show changes in the magnesium/chloride ratios which parallel the 45° slope expected from simple evaporation.

The precipitation of minerals can occur when saturation levels are reached. The WATEQM-SE program indicated gypsum saturation at the center of the east-west traverse along the base of the aquifer and within the tills in the eastern portion of the traverse. Gypsum nodules are located within the silts and tills along the east-west traverse from 130-59-1CCC to 130-59-1DDD. The gypsum probably precipitated when oversaturation occurred and possibly during a major recharge event(s) in which water moved downward into the silts and tills. The precipitation may have been aided by the common ion effect (Freeze and Cherry, 1979,

p.112). If, for example, the descending water was undersaturated with respect to calcite and saturated with gypsum (the situation in February, 1984), and it encountered calcite, the calcite would then dissolve. The dissolution of calcite would release Ca^{2+} into solution. The added Ca^{2+} ions would then increase the total activity of Ca^{2+} causing oversaturation of gypsum (the common ion effect), resulting in precipitation.

The precipitation of iron minerals, pyrite and siderite, require more than just the common ion effect. Low redox conditions are needed for their precipitation. The production of hydrogen sulfide gas also requires a low pe. Low pe conditions for redox reactions necessitate bacterial action to oxidize a reduced form of carbon in the reduction of sulfates to H_2S gas (Drever, 1982, p.281). The presence of lignite in the tills and the aquifer fulfills the reduced carbon requirement in this reaction; however, sulfate reduction in contact with coal is generally a slow process (Drever, 1982, p.292).

Because siderite and pyrite are present in the source rocks of the glacial sediments it can be argued that pyrite and siderite are not precipitated in the sediments, but were transported and emplaced glacially. The only evidence for the converse is the pyrite sample which appears to have formed along a fracture in the tills.

The saline groundwater has probably concentrated over an unknown number of years. The main ionic constituents were probably formed from carbonate and gypsum dissolution, pyrite oxidation, and cation exchange. All of the sediments, the surficial clay, the sands and gravels, the silts, and the tills, individually or combined, have the correct

mineralogy to produce the end result. It is likely that each of the sediments has contributed dissolved constituents to the saline groundwater.

CONCLUSIONS

The following summarizes the conditions that were observed and interpreted during the study period. These conditions are presumed to have evolved since the deposition of the Pleistocene and Holocene sediments. It is possible that changes in water chemistry will continue to occur over the long-term.

Groundwater movement in the Oakes aquifer is spatially and temporally variable. Recharge and discharge in the aquifer are primarily characterized by vertical movements within the unsaturated zone. The general movement of groundwater is a slow east to west flow under low gradients across the glacial lake plain toward the James River. Stable groundwater movement has a lateral component toward the center of the depression and an axial component toward the James River.

Recharge events cause disruptions of the stable flow pattern involving local reversals of gradients. Outward flow from the center of the depression is the typical response of a depression-focused recharge event. Along the east-west traverse, after recharge, flow carried water eastward until stable westward flow returned. Because recharge and stable flow characteristics are contrasting conditions, water within the depression is assumed to oscillate back and forth with no appreciable

movement. Combined with slow axial flow, water movement is expected to form a zig-zag pattern toward the James River. Although the long-term flow patterns are not known, the topography and the results of this study imply that the movements, as stated above, have probably occurred since the formation of the depression.

The groundwater chemistry reflects the type of materials through which the water flows. Magnesium and bicarbonate ions are derived from dissolution of carbonate minerals. Calcium ions are obtained from carbonate and gypsum dissolution. Sodium ions are the result of cation exchange with montmorillonite clays, and sulfate ions can be derived from pyrite oxidation or gypsum dissolution.

Evaporation is the mechanism proposed which concentrates the dissolved solids at the center of the depression. The stable flow pattern involves lateral flow toward the trough and groundwater discharge from the trough by evapotranspiration. Dissolved solids in solution concentrate during evapotranspiration, leading to precipitation of minerals in the surficial clays in the center of the depression. Cation exchange occurs within the surficial clays, releasing sodium into the groundwater in exchange for calcium. Recharge events dissolve and flush precipitated minerals downward to the water table. If the recharging solution is denser than the groundwater it may descend by miscible displacement through the aquifer. The solutes further concentrate in the base of the aquifer as the above processes continue. The concentrations of salts added to the center of the trough are large enough to balance the axial discharge of groundwater from the trough, thus maintaining the saline conditions in the center of the depression.

RECOMMENDATIONS

Throughout the course of this study several questions have been left unanswered. These questions should direct future actions and studies within the area. For example, the age of the water beneath the depression should be determined. Tritium analyses of the water should indicate whether the water is pre- or post-1950 in origin. The results of the tritium analyses could provide data which would verify or refute the evaporative concentration and miscible displacement hypotheses. A study of the isotopic fractionation of hydrogen and oxygen within the saline water would reinforce or refute evaporation as a concentrating mechanism.

Additional piezometers north of the existing north-south traverse would further delineate flow characteristics and water chemistry in that area. Additional piezometers in the lower aquifer in the center of the depression would provide more information on flow in the lower aquifer and its hydraulic connections with the Oakes aquifer.

Further study should be attempted to determine the physical and chemical processes occurring in the unsaturated zone. Nested lysimeters, in conjunction with nested tensiometers and piezometers, should be used to determine the water chemistry of infiltrating water before, during, and after recharge events.

APPENDICES

APPENDIX A

WELL DATA AND LITHOLOGIC LOGS OF USBR WELLS

USBR-198 (130-59-1CCC)
0-1 Topsoil, silt; clayey, black.
1-3 Clay; silty.
3-4 Clay; sandy, silty.
4-5.5 Sand; medium-grained, brown.
5-5.8 Sand; medium-grained, gray.
8-11 Sand; medium- to coarse-grained, gray.
11-26.5 Sand; medium- to very coarse-grained, pebbly, gray.
26.5-28 Sand; fine- to medium-grained, gray.
28-31 Sand; medium- to coarse-grained, gray.
31-33 Clay; silty, sandy, gray.
WELL# USBR-198B screened 16.4-17.6 feet. Well elevation 1310.94 feet.
WELL# USBR-198A screened 26.3-27.3 feet. Well elevation 1310.07 feet.

USBR-199 (130-59-1DDD)
0-1.5 Topsoil, silt; clayey, black.
1.5-2 Clay; silty, sandy, gray (dry).
2-4.5 Clay; silty, laminated, olive-brown (dry).
4.5-7.5 Clay; oxidized sand layers, laminated, olive-brown (dry).
7.5-9.5 Sand; medium-grained, pebbly, oxidized, brown.
9.5-30 Sand; fine- to medium-grained, gray.
30-31 Sand; coarse-grained, gray.
31-33 Sand; medium- to very coarse-grained, pebbly, gray.
WELL# USBR-199B screened 13.4-14.6 feet. Well elevation 1315.71 feet.
WELL# USBR-199A screened 29.2-30.4 feet. Well elevation 1314.92 feet.

USBR-200 (130-58-7CBB)
0-1.5 Topsoil, sand; silty, gray-black.
1.5-2.5 Sand; fine- to medium-grained, silty, light brown, iron oxides.
2.5-3.5 Sand, fine-grained, silty, clayey, light brown, iron oxides.
3.5-5 Sand; fine-grained, silty, clayey, dark brown-green.
5-14 Sand; fine-grained, silty, gray.
14-25 Sand; fine- to medium-grained, lignitic layers (18.5-19.5), gray.
25-29 Sand; very coarse-grained, pebbly, gray.
29-31.5 Gravel; sandy, gray.
31.5-32 Sand; medium-grained, gray.
32-33 Silt; clayey, sandy, laminated, gray.
WELL# USBR-200B screened 13.4-14.6 feet. Well elevation 1310.30 feet.
WELL# USBR-200A screened 28.3-29.5 feet. Well elevation 1310.37 feet.

USBR-201 (130-58-7CCC)
0-1 Topsoil, clay; silty, sandy, black.
1-2.5 Clay; silty, sandy, laminated, gray.
2.5-3.5 Clay; silty, sandy, laminated, brown.
3.5-4.5 Sand; fine- to medium-grained, silty, brown.
4.5-8.5 Sand; fine- to medium-grained, silty, gray.
8.5-12 Sand; medium- to coarse-grained, gray.
12-18 Sand; medium-grained, gray.
WELL# USBR-201 screened 13.7-14.8 feet. Well elevation 1310.16 feet.

USBR-202 (130-58-17CCC)
0-1 Topsoil, sand; silty, dark brown-black.
1-2 Sand; fine-grained, silty, light to medium brown.
2-3.5 Sand; fine- to medium-grained, silty, light brown.

3.5-5 Clay; sandy, silty, laminated, brown.
5-6 Clay; sandy, silty, sand layers, gray.
6-8 Clay; sandy, silty, dark gray.
8-17 Sand; medium-grained, silty, gray.
17-18 Sand; medium-grained, dark gray clay laminations, gray.
WELL# USBR-202B screened 6.8-8.4 feet. Well elevation 1315.35 feet.
WELL# USBR-202A screened 13.2-14.4 feet. Well elevation 1314.98 feet.

USBR-203 (130-58-17BCC)
0-1 Topsoil, sand; fine-grained, silty, dark brown.
1-2 Sand; fine- to medium-grained, silty, brown.
2-3 Silt; sandy, laminated, iron stains, gray to light brown.
3-6 Silt; sandy, laminated, light brown.
6-7 Clay; silty, dark gray.
7-8 Sand; coarse-grained, gray.
8-13 Sand; medium-grained, clay laminations (3 mm thick), gray.
13-16 Sand; medium-grained, gray.
16-19 Sand; fine- to medium-grained, gray.
19-21 Silt; fine-grained sand laminations, gray.
21-22 Silt; gray and brown laminations.
22-23 Sand; coarse-grained, brown.
23-27 Sand; coarse-grained, gray.
27-29 Sand; coarse-grained, shaly, dark gray.
29-33 Sand; coarse-grained, gray.
WELL# USBR-203C screened 4.9-6.1 feet. Well elevation 1315.93 feet.
WELL# USBR-203B screened 15.8-16.9 feet. Well elevation 1315.04 feet.
WELL# USBR-203A screened 27.7-28.9 feet. Well elevation 1315.79 feet.

USBR-204 (130-58-17BBB)
0-1 Topsoil, silt; black.
1-1.5 Silt; clayey, laminated, dark gray.
1.5-2.5 Silt; clayey, light gray.
2.5-3 Silt; sandy, white.
3-7 Silt; clayey, dark gray laminations, brown to gray.
7-9 Clay; silty, brown silty laminations, selenite crystals, gray.
9-16.5 Clay; sand laminations (13 feet), selenite crystals (9-11 feet), dark gray.
16.5-17 Sand; fine-grained, silty, gray.
17-25 Sand; fine- to medium-grained, silty, clay laminations (19-22 feet, 3-5 mm thick), gray.
25-28 Sand; coarse-grained, brown.
WELL# USBR-204C screened 7.1-8.2 feet. Well elevation 1315.41 feet.
WELL# USBR-204B screened 16.8-18.0 feet. Well elevation 1315.39 feet.

USBR-205 (130-58-18DBB)
0-1 Topsoil, silt; sandy, black.
1-1.5 Sand; fine-grained, dark gray.
1.5-6 Sand; fine-grained, silty, white and dark gray laminations (4-6 feet), brown.
6-10.5 Silt; clayey, sandy, dark gray laminations (6-6.5 feet), iron oxides (7.5-8 feet), shell fragments, brown plant fragments (10-10.5 feet), gray.
10.5-14.5 Silt; sandy, sand laminations (8 inches apart), dark gray.
14.5-33 Sand; medium-grained, gray.

WELL# USBR-205B screened 14.4-15.6 feet. Well elevation 1315.95 feet.
WELL# USBR-205A screened 29.8-31.0 feet. Well elevation 1313.99 feet.

USBR-206 (130-58-18DCC)
0-2 Topsoil, silt; black to gray.
2-4 Sand; fine-grained, silty, dark gray silt layer at 3.5 feet, iron oxide layer at 3.75 feet, brown.
4-4.5 Silt; sandy, orange laminations, dark gray.
4.5-5.5 Silt; white and gray laminations (5-5.5 feet), gray-white.
5.5-6 Silt; white laminations, dark gray.
6-13.5 Sand; fine- to medium-grained, gray.
13.5-17.5 Sand; fine- to coarse-grained, lignitic pebbles, gray.
17.5-34 Sand; fine- to coarse-grained, gray.
WELL# USBR-206 screened 16.0-17.2 feet. Well elevation 1312.78 feet.

USBR-207 (130-58-19BBB)
0-1 Topsoil, silt; sandy, black.
1-2 Sand; fine-grained, silty, light brown.
2-3 Sand; fine-grained, silty, light green-light brown.
3-5 Sand; fine-grained, silty, iron oxide layers (4-4.5 feet), gray.
5-32.5 Sand; medium- to coarse-grained, lignitic sand (7.5-9 and 20.5-21 feet), gray.
32.5-33.5 Silt; sandy, gray.
WELL# USBR-207 screened 18.8-20.0 feet. Well elevation 1312.39 feet.

USBR-208 (130-58-17CDD)
0-1 Topsoil, sand; black.
1-3 Sand; fine-grained, silty, iron oxides (2-3 feet), light brown.
3-14 Sand; fine- to medium-grained, shaly (12-13 feet), brown.
14-18 Sand; fine- to coarse-grained, brown-gray.
18-33 Sand; medium- to coarse-grained, lignitic (23.5-25.5 feet), gray.
WELL# USBR-208 screened 17.9-19.1 feet. Well elevation 1316.40 feet.

USBR-209 (130-58-17BAA)
0-3 Topsoil, silt; sandy, black.
3-5 Sand; fine-grained, silty, white.
5-7 Silt; sandy, brown-white laminations, iron oxide (6-7 feet), brown.
7-8 Sand; medium-grained, pebbly, brown.
8-11 Sand; medium-grained, white-brown.
11-14.5 Sand; fine- to medium-grained, silty, brown.
14.5-23.5 Sand; fine- to medium-grained, silty, gray.
23.5-33 Sand; coarse-grained, gray.
WELL# USBR-209 screened 24.8-26.0 feet. Well elevation 1322.24 feet.

USBR-210 (130-58-19ADD)
0-1 Topsoil, sand; silty, black.
1-3.5 Sand; fine-grained, silty, light brown.
3.5-4 Sand; fine- to medium-grained, silty, iron oxide, gray-green.
4-5 Silt; sand laminations, iron oxides, gray.
5-6.5 Clay; silty, sand layers, dark gray.
6.5-30 Sand; medium-grained, silty, silt layers (11.5-12 and 29.5-30 feet), gray.
30-32 Sand; medium- to coarse-grained, gray.
WELL# USBR-210 screened 18.3-19.5 feet. Well elevation 1314.89 feet.

USBR-211 (130-58-18BCC)
0-2 Topsoil, silt; sandy, black.
2-4 Sand; fine-grained, silty, light brown.
4-7.5 Sand; fine- to medium-grained, silty, brown.
7.5-16 Sand; medium- to coarse-grained, shaly (8-9 feet), gray.
16-25.5 Sand; fine-grained, silty, gray.
25.5-34 Sand; coarse-grained, gray.
WELL# USBR-211 screened 17.4-18.6 feet. Well elevation 1313.70 feet.

USBR-212 (130-59-12DCC)
0-1 Topsoil, silt; sandy, clayey, snail shells, black.
1-4 Silt; clayey, sandy, snail shells, brown.
4-5 Sand; medium-grained, brown.
5-6 Sand; fine-grained, silty, gray.
6-20 Sand; medium- to coarse-grained, silty, gray.
20-28 Sand; coarse-grained, gray.
28-31 Sand; fine- to medium-grained, gray.
31-33 Sand; coarse-grained, gray.
WELL# USBR-212B screened 4.7-5.9 feet. Well elevation 1309.53 feet.
WELL# USBR-212A screened 17.0-18.2 feet. Well elevation 1309.65 feet.

USBR-213 (130-59-13BCC)
0-1 Topsoil, silt; sandy, black.
1-3 Sand; fine-grained, silty, iron oxide, brown.
3-4.5 Sand; medium- to coarse-grained, silty, iron oxide, brown.
4.5-5 Sand; very coarse-grained, gray.
5-14 Sand; coarse-grained, gray.
14-23.5 Sand; fine- to medium-grained, gray.
23.5-25.5 Sand; coarse-grained, gray
25.5-26.5 Sand; fine- to medium-grained, gray.
26.5-27.5 Sand; coarse-grained, gray.
27.5-30 Sand; fine- to coarse-grained, shaly, gray.
30-33 Sand; coarse-grained, pebbly, gray.
WELL# USBR-213 screened 17.4-18.9 feet. Well elevation 1311.97 feet.

USBR-214 (130-59-13BBB)
0-1.5 Topsoil, silt; sandy, dark gray-black.
1.5-5 Sand; fine- to medium-grained, iron oxide (4-5 feet), brown.
5-12.5 Sand; medium-grained, gray.
12.5-13.5 Sand; fine-grained, gray.
13.5-14 Sand; medium-grained, gray.
14-15 Sand; coarse-grained, gray.
15-24 Sand; very coarse-grained, gray.
WELL# USBR-214 screened 18.4-19.6 feet. Well elevation 1310.65 feet.

APPENDIX B

WELL DATA AND LITHOLOGIC LOGS OF NDSWC WELLS

130-59-1CCC
0-5 Clay; silty, red-yellow-brown stringers, oxidized, light gray.
5-8 Sand; very fine- to very coarse-grained, lignitic, shaly, 5-10% shield silicates, 10% carbonates, subangular-well rounded, oxidized, yellow-stained.
8-31 Sand; very fine- to coarse-grained, gravelly, gray.
31-57 Silt; clayey, gravel-size gypsum nodules (37 feet), gray.
57-60 Clay; silty, sandy, pebbly, olive-gray (Till).
WELL# SWC-12286 screened 4-9 feet. Well elevation 1310.32 feet.
WELL# SWC-12297 screened 59-60 feet. Well elevation 1310.47 feet.

130-59-1CCD
0-5 Clay; silty, oxidized, red-yellow-brown stringers, light gray.
5-6 Sand; very fine- to very coarse-grained, oxidized, yellow-stained.
6-55 Sand; very fine- to very coarse-grained, gravelly, drills as stratified, 5-10% shield silicates, 10% carbonates, detrital shale and quartz, gray.
55-56 Clay; silty, sandy, pebbly, olive-gray (Till).
WELL# SWC-12298 screened 53-54 feet. Well elevation 1309.76 feet.
WELL# SWC-12299 screened 29-30 feet. Well elevation 1309.74 feet.
WELL# SWC-12300 screened 5-10 feet. Well elevation 1309.73 feet.

130-59-1CDD
0-6 Clay; silty, red-yellow-brown stringers, oxidized, light gray-brownish gray.
6-9 Sand; very fine- to coarse-grained, predominantly shale and quartz, 5-10% shield silicates, 5-10% carbonates, lignitic, oxidized, yellow stained.
9-13 Sand; same as above, unoxidized, gray.
13-29 Sand; very fine- to very coarse-grained, gravelly, gray.
29-56 Silt; clayey, varved, greenish-gray.
56-76 Clay; silty, sandy, pebbly, olive-gray (Till).
76-88 Gravel; fine- to very coarse-pebble, most samples composed of light brown carbonate with gray shale.
88-109 Clay; silty, sandy, pebbly, olive-gray (Till).
WELL# SWC-11920 screened 80-83 feet. Well elevation 1311.39 feet.
WELL# SWC-11920A screened 20-25 feet. Well elevation 1311.42 feet.
WELL# SWC-12287 screened 5-11 feet. Well elevation 1312.03 feet.
WELL# SWC-12293 screened 59-60 feet. Well elevation 1312.53 feet.

130-59-1DDD
0-9 Clay; silty, red-yellow-brown stringers, oxidized, light gray.
9-12 Sand; very fine- to coarse, 10% shield silicates, lignitic, oxidized, yellow stained.
12-32 Sand; as above, unoxidized, gray.
32-42 Sand; very fine- to very coarse-grained, gravelly, gray.
42-60 Silt; clayey, gypsum nodules at 42-44 feet, greenish-gray.
WELL# SWC-12291 screened 59-60 feet. Well elevation 1315.22 feet.
WELL# SWC-12292 screened 39-41 feet. Well elevation 1314.92 feet.

130-59-2BBB
0-8 Clay; silty, yellow-brown-red stringers, oxidized, light gray.

8-14 Sand; very fine- to coarse-grained, lignitic, 5-10% shield silicates, 10% carbonates, oxidized, yellow stained.
14-15 Sand; as above, unoxidized, gray.
15-17 Clay; silty, unoxidized, greenish-gray.
17-38 Sand; very fine- to very coarse-grained, 5-10% shield silicates, 10% carbonates, shaly, gray.
38-60 Clay, silty, sandy, pebbly, olive-gray (Till).
WELL# SWC-12282 screened 36-37 feet. Well elevation 1316.38 feet.
WELL# SWC-12283 screened 11-15 feet. Well elevation 1317.36 feet.
WELL# SWC-12301 screened 59-60 feet. Well elevation 1316.57 feet.

130-59-2BCB
0-10 Clay; silty, red-yellow stringers, oxidized, pale greenish-gray.
10-11 Clay; as above, unoxidized, olive-gray.
11-22 Sand; very fine- to very coarse-grained, shaly, 5-10% shield silicates, 10-20% carbonates, 5% lignite.
22-30 Sand; as above, 10-20% gravel.
30-31 Clay; silty, sandy, pebbly, olive-gray (Till).
WELL# SWC-12280 screened 28-29 feet. Well elevation 1311.18 feet.
WELL# SWC-12281 screened 12-14 feet. Well elevation 1311.17 feet.

130-59-2CBB
0-8 Clay; silty, sandy, red-yellow stained, oxidized, dark brown-pale greenish-gray.
8-13 Silt; clayey, poor sample return, greenish-gray.
13-32 Sand; very fine- to coarse-grained, shaly, 5-10% shield silicates, 10-15% carbonates, lignitic, unoxidized.
32-60 Clay; silty, sandy, pebbly, olive-gray (Till).
WELL# SWC-12278 screened 30-31 feet. Well elevation 1311.32 feet.
WELL# SWC-12279 screened 14-16 feet. Well elevation 1311.36 feet.
WELL# SWC-12302 screened 59-60 feet. Well elevation 1311.92 feet.

130-59-2CCB
0-8 Clay; silty, red-yellow-brown stringers, oxidized, light gray-brownish gray.
8-11 Sand; very fine- to coarse-grained, shaly, 5-10% shield silicates, 5-10% carbonates, oxidized, yellow stained.
11-37 Sand; as above, 5-10% gravel, unoxidized, gray.
37-60 Clay; silty, sandy, pebbly, olive-gray (Till).
WELL# SWC-12276 screened 36-37 feet. Well elevation 1312.94 feet.
WELL# SWC-12304 screened 8-13 feet. Well elevation 1312.59 feet.
WELL# SWC-12303 screened 58-59 feet. Well elevation 1313.79 feet.

130-59-2CDD
0-9 Clay; silty, red-yellow-brown stringers, oxidized, light gray.
9-12 Sand; very fine- to coarse-grained, shaly, 5-10% silicates, 5-10% carbonates, oxidized, yellow stained.
12-23 Sand; as above, unoxidized, gray.
23-41 Sand; as above, gravelly, gray.
41-60 Clay; silty, sandy, pebbly, olive-gray (Till), a couple of pieces of greenish-gray silty clay from 41-44 feet.
WELL# SWC-12284 screened 38-39 feet. Well elevation 1315.41 feet.
WELL# SWC-12285 screened 10-18 feet. Well elevation 1315.86 feet.
WELL# SWC-12294 screened 59-60 feet. Well elevation 1316.16 feet.

130-59-2DDC
0-6 Clay; silty, red-yellow-brown stringers, oxidized, light gray.
6-10 Sand; very fine- to very coarse-grained, shaly, 5-10% shield silicates, 5% carbonates, lignitic, oxidized, yellow stained.
10-25 Sand; as above, unoxidized, gray.
25-31 Sand; as above, gravelly.
31-32 Clay; silty, greenish-gray.
WELL# SWC-12295 screened 29-30 feet. Well elevation 1312.60 feet.
WELL# SWC-12296 screened 6-14 feet. Well elevation 1313.03 feet.

130-59-11BBB
0-9 Clay; silty, pale yellow-brown.
9-14 Sand; very fine- to very coarse-grained, gravelly, shaly, 10% silicates, oxidized, yellow stained.
14-24 Sand; as above, unoxidized, gray.
24-26 Gravel; sandy, same composition as sand above.
26-40 Sand; fine- to medium-grained.
40-60 Clay; silty, sandy, pebbly, olive-gray (Till).
WELL# SWC-12274 screened 35-36 feet. Well elevation 1315.34 feet.
WELL# SWC-12275 screened 9-17 feet. Well elevation 1315.55 feet.
WELL# SWC-12289 screened 57-58 feet. Well elevation 1315.40 feet.

APPENDIX C

CALCULATED HYDRAULIC CONDUCTIVITY VALUES (K)

Well	K Value (cm/s)	K Value (gal/day/ft2)	Lithologic Type
USBR #			
200B	7.5x10-3	160.00	Sand,fine-medium
202A	5.2x10-3	110.00	Sand,medium
203B	9.6x10-4	20.00	Sand,fine-medium
204B	3.1x10-3	66.00	Sand,fine-medium
209	7.9x10-3	170.00	Sand,coarse
210	1.6x10-2	340.00	Sand,medium
211	1.4x10-2	300.00	Sand,fine
SWC #			
12274	8.2x10-4	17.00	Sand,fine-medium
12278	4.3x10-2	910.00	Sand,fine-medium
12280	7.9x10-2	1,700.00	Sand and gravel
12289	4.2x10-5	0.89	Till
12291	2.8x10-7	0.01	Lacustrine silt
12293	5.0x10-5	1.10	Till
12294	7.8x10-4	17.00	Till
12297	6.6x10-4	14.00	Till
12301	9.1x10-5	1.90	Till
12302	1.9x10-5	0.40	Till
12303	3.0x10-5	0.64	Till

APPENDIX D

WATER CHEMISTRY

OF USBR AND NDSWC WELLS

Water Chemistry

USBR-200A — WELL # | 130-58-7CBB — LOCATION | 28.3-29.5 ft. — SCREENED INTERVAL

PARAMETER	DATE 1 5-31-83	DATE 2 10-30-83	DATE 3 2-24-84	DATE 4 5-15-84
FIELD pH	7.0	6.4	6.7	6.8
LAB pH	7.8	8.0	7.9	7.7
FIELD TEMP	8.0	8.6	7.6	8.0
FIELD COND	4000.	2700.	2500.	-
LAB COND	5680.	6800.	6340.	3670.
SILICA	26.	27.	29.	30.
CALCIUM	210.	350.	250.	95.
MAGNESIUM	370.	480.	410.	170.
POTASSIUM	59.	58.	65.	41.
SODIUM	830.	940.	890.	570.
FLUORIDE	0.2	0.2	0.2	0.2
BICARBONATE	646.	672.	688.	643.
CARBONATE	0.	0.	0.	0.
SULFATE	3200.	4100.	3600.	1700.
CHLORIDE	20.	22.	21.	10.
NITRATE	1.	4.3	1.	3.3
BORON	0.44	0.27	0.40	0.53
IRON	5.0	7.2	2.8	2.8
MANGANESE	0.80	0.92	0.89	0.40
SAR	8.1	7.6	8.1	8.1
TDS	5040.	6320.	5610.	2940.
ION BALANCE	0.47%	1.15%	0.15%	1.87%
SAMPLED	bailed	pumped	pumped	bailed
REMARKS	-	rust	rust	-

Water Chemistry

USBR-200B	130-58-7CBB	13.4-14.6 ft.
WELL #	LOCATION	SCREENED INTERVAL

PARAMETER	DATE 1 5-31-83	DATE 2 10-30-83	DATE 3 2-24-84	DATE 4 5-15-84
FIELD pH	7.0	6.9	7.0	6.9
LAB pH	7.9	7.9	7.8	7.8
FIELD TEMP	7.3	10.2	7.1	5.0
FIELD COND	2300.	750.	1030.	-
LAB COND	2740.	1160.	1270.	1290.
SILICA	26.	30.	30.	29.
CALCIUM	200.	97.	110.	110.
MAGNESIUM	180.	76.	82.	83.
POTASSIUM	26.	14.	13.	13.
SODIUM	210.	66.	65.	69.
FLUORIDE	0.1	0.1	0.1	0.1
BICARBONATE	560.	418.	461.	462.
CARBONATE	0.	0.	0.	0.
SULFATE	1200.	320.	350.	380.
CHLORIDE	25.	5.3	7.2	4.9
NITRATE	1.	1.1	1.	1.0
BORON	0.12	0.10	0.13	0.13
IRON	1.6	0.95	0.12	0.52
MANGANESE	2.2	1.9	2.1	1.9
SAR	2.6	1.2	1.1	1.2
TDS	2150.	818.	888.	921.
ION BALANCE	0.43%	2.25%	1.05%	0.00%
SAMPLED	bailed	pumped	pumped	bailed
REMARKS	-	-	-	-

Water Chemistry

USBR-201	130-58-7CCC	13.7-14.8 ft.
WELL #	LOCATION	SCREENED INTERVAL

PARAMETER	DATE 1	DATE 2	DATE 3	DATE 4
	5-31-83	10-30-83	2-24-84	5-15-84
FIELD pH	7.1	6.7	7.1	6.8
LAB pH	7.9	7.9	7.9	7.6
FIELD TEMP	6.2	9.5	6.3	5.0
FIELD COND	2600.	1010.	1180.	-
LAB COND	3360.	1570.	1630.	1620.
SILICA	26.	30.	29.	28.
CALCIUM	220.	150.	140.	140.
MAGNESIUM	140.	70.	62.	62.
POTASSIUM	31.	15.	15.	14.
SODIUM	420.	150.	150.	150.
FLUORIDE	0.3	0.2	0.2	0.2
BICARBONATE	588.	483.	557.	558.
CARBONATE	0.	0.	0.	0.
SULFATE	1500.	500.	470.	480.
CHLORIDE	25.	7.6	6.8	4.9
NITRATE	1.0	2.9	1.	2.1
BORON	0.28	0.27	0.34	0.34
IRON	0.86	1.3	0.77	1.1
MANGANESE	1.3	1.1	1.1	1.1
SAR	5.5	2.5	2.6	2.6
TDS	2660.	1170.	1150.	1160.
ION BALANCE	0.07%	4.02%	0.37%	0.89%
SAMPLED	bailed	pumped	pumped	bailed
REMARKS	-	-	-	-

Water Chemistry

USBR-209 WELL # | 130-58-17BAA LOCATION | 24.8-26.0 ft. SCREENED INTERVAL

PARAMETER	DATE 1 5-30-83	DATE 2 11-4-83	DATE 3 2-24-84	DATE 4 4-24-84
FIELD pH	6.6	6.7	7.2	6.7
LAB pH	7.8	7.7	7.4	7.6
FIELD TEMP	7.0	8.1	7.7	8.3
FIELD COND	880.	660.	780.	590.
LAB COND	874.	729.	847.	836.
SILICA	25.	31.	30.	26.
CALCIUM	110.	130.	120.	120.
MAGNESIUM	37.	37.	34.	35.
POTASSIUM	8.5	7.7	7.6	7.7
SODIUM	24.	9.5	10.	13.
FLUORIDE	0.3	0.4	0.3	0.3
BICARBONATE	382.	389.	513.	472.
CARBONATE	0.	0.	0.	0.
SULFATE	130.	87.	52.	84.
CHLORIDE	29.	4.3	3.8	2.3
NITRATE	1.	1.	1.	0.3
BORON	0.12	0.10	0.10	0.11
IRON	0.02	0.12	0.08	0.10
MANGANESE	0.32	0.85	0.91	0.92
SAR	0.5	0.2	0.2	0.3
TDS	553.	501.	513.	523.
ION BALANCE	0.20%	9.68%	1.15%	0.36%
SAMPLED	bailed	pumped	pumped	bailed
REMARKS	-	-	-	-

Water Chemistry

USBR-204B — WELL #
130-58-17BBB — LOCATION
16.8-18.0 ft. — SCREENED INTERVAL

PARAMETER	DATE 1	DATE 2	DATE 3	DATE 4
	5-30-83	-	-	-
FIELD pH	7.1	-	-	-
LAB pH	8.1	-	-	-
FIELD TEMP	7.2	-	-	-
FIELD COND	3000.	-	-	-
LAB COND	3680.	-	-	-
SILICA	30.	-	-	-
CALCIUM	250.	-	-	-
MAGNESIUM	230.	-	-	-
POTASSIUM	24.	-	-	-
SODIUM	380.	-	-	-
FLUORIDE	0.2	-	-	-
BICARBONATE	265.	-	-	-
CARBONATE	0.	-	-	-
SULFATE	2100.	-	-	-
CHLORIDE	9.6	-	-	-
NITRATE	1.0	-	-	-
BORON	0.13	-	-	-
IRON	0.07	-	-	-
MANGANESE	0.94	-	-	-
SAR	4.1	-	-	-
TDS	3160.	-	-	-
ION BALANCE	0.19%	-	-	-
SAMPLED	bailed	-	-	-
REMARKS	-	-	-	-

Water Chemistry

USBR-204C — WELL #
130-58-17BBB — LOCATION
7.1-8.2 ft. — SCREENED INTERVAL

PARAMETER	DATE 1	DATE 2	DATE 3	DATE 4
	5-30-83	-	-	-
FIELD pH	7.7	-	-	-
LAB pH	7.5	-	-	-
FIELD TEMP	7.3	-	-	-
FIELD COND	6200.	-	-	-
LAB COND	12,200.	-	-	-
SILICA	11.	-	-	-
CALCIUM	600.	-	-	-
MAGNESIUM	1400.	-	-	-
POTASSIUM	41.	-	-	-
SODIUM	1200.	-	-	-
FLUORIDE	0.2	-	-	-
BICARBONATE	314.	-	-	-
CARBONATE	0.	-	-	-
SULFATE	9300.	-	-	-
CHLORIDE	21.	-	-	-
NITRATE	5.8	-	-	-
BORON	0.10	-	-	-
IRON	0.08	-	-	-
MANGANESE	0.06	-	-	-
SAR	6.1	-	-	-
TDS	12,700.	-	-	-
ION BALANCE	0.3%	-	-	-
SAMPLED	bailed	-	-	-
REMARKS	-	-	-	-

Water Chemistry

USBR-203C	130-58-17BCC	4.9-6.1 ft.
WELL #	LOCATION	SCREENED INTERVAL

PARAMETER	DATE 1	DATE 2	DATE 3	DATE 4
	-	-	-	4-25-84
FIELD pH	-	-	-	6.4
LAB pH	-	-	-	7.6
FIELD TEMP	-	-	-	5.0
FIELD COND	-	-	-	750.
LAB COND	-	-	-	1100.
SILICA	-	-	-	14.
CALCIUM	-	-	-	40.
MAGNESIUM	-	-	-	64.
POTASSIUM	-	-	-	73.
SODIUM	-	-	-	85.
FLUORIDE	-	-	-	0.3
BICARBONATE	-	-	-	556.
CARBONATE	-	-	-	0.
SULFATE	-	-	-	110.
CHLORIDE	-	-	-	13.
NITRATE	-	-	-	26.
BORON	-	-	-	0.47
IRON	-	-	-	0.02
MANGANESE	-	-	-	0.02
SAR	-	-	-	1.9
TDS	-	-	-	700.
ION BALANCE	-	-	-	2.48%
SAMPLED	-	-	-	bailed
REMARKS	-	-	-	pH rose fast color: yellow

Water Chemistry

USBR-203B	130-58-17BCC	15.8-16.9 ft.
WELL #	LOCATION	SCREENED INTERVAL

PARAMETER	DATE 1	DATE 2	DATE 3	DATE 4
	5-30-83	11-4-83	2-25-84	4-25-84
FIELD pH	7.1	6.6	5.8	6.7
LAB pH	7.8	7.9	7.7	7.7
FIELD TEMP	6.6	8.2	5.5	6.6
FIELD COND	2200.	630.	740.	750.
LAB COND	2280.	805.	818.	797.
SILICA	12.	31.	30.	24.
CALCIUM	330.	97.	100.	100.
MAGNESIUM	120.	38.	38.	36.
POTASSIUM	18.	7.8	7.7	6.1
SODIUM	190.	30.	26.	23.
FLUORIDE	0.2	0.3	0.2	0.2
BICARBONATE	309.	396.	395.	425.
CARBONATE	0.	0.	0.	0.
SULFATE	1100.	100.	93.	72.
CHLORIDE	32.	23.	22.	17.
NITRATE	1.	1.7	1.	0.2
BORON	0.08	0.12	0.12	0.13
IRON	0.74	0.58	0.21	0.33
MANGANESE	1.4	0.88	0.80	0.69
SAR	2.3	0.7	0.6	0.5
TDS	1960.	528.	514.	489.
ION BALANCE	9.66%	1.12%	2.11%	0.83%
SAMPLED	bailed	pumped	pumped	bailed
REMARKS	-	-	-	-

Water Chemistry

USBR-203A	130-58-17BCC	27.7-28.9 ft.
WELL #	LOCATION	SCREENED INTERVAL

PARAMETER	DATE 1 5-30-83	DATE 2 11-4-83	DATE 3 2-25-84	DATE 4 4-25-84
FIELD pH	7.1	6.7	5.4	6.6
LAB pH	7.8	8.0	7.7	7.5
FIELD TEMP	7.6	7.6	5.6	7.6
FIELD COND	920.	680.	730.	580.
LAB COND	852.	903.	885.	853.
SILICA	26.	29.	29.	19.
CALCIUM	81.	120.	170.	110.
MAGNESIUM	36.	34.	33.	34.
POTASSIUM	7.4	7.3	7.2	7.1
SODIUM	29.	27.	27.	27.
FLUORIDE	0.2	0.2	0.2	0.2
BICARBONATE	337.	390.	395.	377.
CARBONATE	0.	0.	0.	0.
SULFATE	150.	120.	120.	110.
CHLORIDE	29.	34.	32.	31.
NITRATE	1.	1.	1.	0.9
BORON	0.13	0.11	0.13	0.12
IRON	0.03	0.95	0.55	0.60
MANGANESE	0.03	0.78	0.75	0.63
SAR	0.7	0.6	0.6	0.6
TDS	526.	566.	566.	527.
ION BALANCE	5.79%	1.35%	0.75%	1.47%
SAMPLED	bailed	pumped	pumped	bailed
REMARKS	-	-	-	-

Water Chemistry

USBR-202B	130-58-17CCC	6.8-8.4 ft.
WELL #	LOCATION	SCREENED INTERVAL

PARAMETER	DATE 1	DATE 2	DATE 3	DATE 4
	5-30-83	11-5-83	-	4-26-84
FIELD pH	7.1	6.6	-	7.3
LAB pH	8.2	7.9	-	7.9
FIELD TEMP	7.7	10.3	-	5.9
FIELD COND	620.	520.	-	520.
LAB COND	478.	725.	-	633.
SILICA	29.	37.	-	19.
CALCIUM	16.	96.	-	59.
MAGNESIUM	30.	29.	-	43.
POTASSIUM	5.3	6.8	-	14.
SODIUM	17.	20.	-	12.
FLUORIDE	0.3	0.3	-	0.5
BICARBONATE	260.	434.	-	410.
CARBONATE	0.	0.	-	0.
SULFATE	48.	40.	-	16.
CHLORIDE	6.7	1.2	-	1.1
NITRATE	1.0	1.	-	3.7
BORON	0.11	0.15	-	0.11
IRON	0.01	0.17	-	0.01
MANGANESE	0.60	0.94	-	0.02
SAR	0.4	0.5	-	0.3
TDS	342.	447.	-	370.
ION BALANCE	13.06%	1.29%	-	1.31%
SAMPLED	bailed	bailed	-	bailed
REMARKS	-	mud	-	-

Water Chemistry

USBR-202A WELL # | 130-58-17CCC LOCATION | 13.2-14.4 ft. SCREENED INTERVAL

PARAMETER	DATE 1 5-30-83	DATE 2 11-4-83	DATE 3 2-25-84	DATE 4 4-25-84
FIELD pH	7.0	6.8	5.8	6.8
LAB pH	7.8	7.8	7.9	7.7
FIELD TEMP	6.1	9.6	6.2	6.2
FIELD COND	1230.	490.	670.	480.
LAB COND	1240.	573.	569.	570.
SILICA	28.	34.	33.	20.
CALCIUM	130.	75.	71.	81.
MAGNESIUM	47.	22.	20.	21.
POTASSIUM	12.	5.8	5.0	5.5
SODIUM	83.	17.	14.	16.
FLUORIDE	0.2	0.2	0.2	0.2
BICARBONATE	368.	350.	358.	358.
CARBONATE	0.	0.	0.	0.
SULFATE	400.	22.	19.	20.
CHLORIDE	6.7	2.0	3.4	1.4
NITRATE	1.0	1.5	1.	0.8
BORON	0.10	0.11	0.11	0.10
IRON	2.3	1.8	0.50	1.3
MANGANESE	1.1	0.68	0.55	0.68
SAR	1.6	0.4	0.4	0.4
TDS	892.	354.	344.	344.
ION BALANCE	1.04%	1.18%	3.81%	2.01%
SAMPLED	bailed	pumped	pumped	bailed
	-	-	-	-

Water Chemistry

USBR-208	130-58-17CDD	17.9-19.1 ft.
WELL #	LOCATION	SCREENED INTERVAL

PARAMETER	DATE 1 5-30-83	DATE 2 11-4-83	DATE 3 2-25-84	DATE 4 4-25-84
FIELD pH	7.9	6.8	5.8	6.9
LAB pH	8.3	7.8	7.9	7.7
FIELD TEMP	6.3	8.4	5.6	5.8
FIELD COND	480.	410.	440.	460.
LAB COND	462.	441.	440.	531.
SILICA	12.	30.	29.	18.
CALCIUM	64.	64.	65.	80.
MAGNESIUM	17.	16.	17.	20.
POTASSIUM	3.0	2.6	2.9	3.2
SODIUM	3.5	3.5	3.6	4.5
FLUORIDE	0.2	0.2	0.2	0.2
BICARBONATE	257.	237.	243.	292.
CARBONATE	0.	0.	0.	0.
SULFATE	26.	28.	26.	31.
CHLORIDE	15.	9.4	8.0	11.
NITRATE	1.	0.8	1.	1.
BORON	0.04	0.03	0.03	0.02
IRON	0.09	0.46	0.04	0.30
MANGANESE	0.67	0.71	0.61	0.83
SAR	0.1	0.1	0.1	0.1
TDS	270.	273.	273.	314.
ION BALANCE	3.8%	0.21%	0.93%	1.20%
SAMPLED	bailed	pumped	pumped	bailed
REMARKS	-	-	-	-

Water Chemistry

USBR-211 WELL #

130-58-18BCC LOCATION

17.4-18.6 ft. SCREENED INTERVAL

PARAMETER	DATE 1 5-31-83	DATE 2 10-30-83	DATE 3 2-24-84	DATE 4 4-25-84
FIELD pH	7.1	7.1	7.2	6.6
LAB pH	8.3	8.2	8.0	7.5
FIELD TEMP	7.2	10.0	6.7	7.0
FIELD COND	1130.	570.	810.	620.
LAB COND	1100.	811.	839.	846.
SILICA	27.	30.	30.	19.
CALCIUM	98.	75.	77.	76.
MAGNESIUM	71.	49.	51.	49.
POTASSIUM	13.	9.4	9.7	9.7
SODIUM	87.	34.	31.	33.
FLUORIDE	0.2	0.2	0.2	0.2
BICARBONATE	294.	445.	446.	433.
CARBONATE	0.	0.	0.	0.
SULFATE	360.	74.	86.	96.
CHLORIDE	22.	11.	16.	16.
NITRATE	1.	1.	1.	1.
BORON	0.15	0.09	0.13	0.12
IRON	0.67	1.1	0.67	0.70
MANGANESE	1.9	1.6	1.6	1.4
SAR	1.6	0.7	0.7	0.7
TDS	827.	505.	524.	515.
ION BALANCE	6.72%	1.71%	0.31%	0.37%
SAMPLED	bailed	pumped	pumped	bailed
REMARKS	-	-	-	-

Water Chemistry

USBR-205A	130-58-18DBB	29.8-31.0 ft.
WELL #	LOCATION	SCREENED INTERVAL

PARAMETER	DATE 1	DATE 2	DATE 3	DATE 4
	5-30-83	10-30-83	2-24-84	-
FIELD pH	7.1	6.8	7.1	-
LAB pH	8.0	8.0	7.8	-
FIELD TEMP	7.5	8.2	7.0	-
FIELD COND	930.	590.	770.	-
LAB COND	914.	678.	734.	-
SILICA	26.	28.	30.	-
CALCIUM	94.	89.	86.	-
MAGNESIUM	40.	29.	27.	-
POTASSIUM	8.3	6.6	7.2	-
SODIUM	43.	30.	30.	-
FLUORIDE	0.3	0.2	0.2	-
BICARBONATE	383.	339.	390.	-
CARBONATE	0.	0.	0.	-
SULFATE	170.	81.	77.	-
CHLORIDE	24.	5.5	8.9	-
NITRATE	1.	1.5	1.	-
BORON	0.16	0.15	0.19	-
IRON	0.01	0.10	0.17	-
MANGANESE	0.32	0.60	0.57	-
SAR	0.9	0.7	0.7	-
TDS	596.	439.	460.	-
ION BALANCE	2.33%	5.52%	1.66%	-
SAMPLED	bailed	bailed	pumped	-
REMARKS	-	-	-	-

Water Chemistry

USBR-205B	130-58-18DBB	14.4-15.6 ft.
WELL #	LOCATION	SCREENED INTERVAL

PARAMETER	DATE 1	DATE 2	DATE 3	DATE 4
	5-30-83	10-30-83	2-24-84	-
FIELD pH	7.6	6.8	7.3	-
LAB pH	8.0	8.0	8.1	-
FIELD TEMP	6.5	10.1	6.7	-
FIELD COND	940.	860.	820.	-
LAB COND	887.	1210.	853.	-
SILICA	29.	30.	28.	-
CALCIUM	90.	130.	89.	-
MAGNESIUM	45.	69.	40.	-
POTASSIUM	6.3	9.9	7.6	-
SODIUM	30.	70.	42.	-
FLUORIDE	0.3	0.3	0.3	-
BICARBONATE	422.	390.	435.	-
CARBONATE	0.	0.	0.	-
SULFATE	140.	330.	110.	-
CHLORIDE	15.	27.	3.7	-
NITRATE	1.	1.5	1.	-
BORON	0.19	0.22	0.20	-
IRON	0.03	0.10	0.03	-
MANGANESE	0.31	0.41	0.25	-
SAR	0.6	1.2	0.9	-
TDS	565.	860.	536.	-
ION BALANCE	3.16%	4.77%	0.98%	-
SAMPLED	bailed	pumped	pumped	-
REMARKS	-	-	-	-

Water Chemistry

USBR-206	130-58-18DCC	16.0-17.2 ft.
WELL #	LOCATION	SCREENED INTERVAL

PARAMETER	DATE 1	DATE 2	DATE 3	DATE 4
	5-30-83	11-4-83	2-25-84	4-26-84
FIELD pH	6.5	6.8	6.3	7.1
LAB pH	7.9	8.1	7.8	7.6
FIELD TEMP	6.3	8.3	5.2	5.8
FIELD COND	870.	560.	580.	540.
LAB COND	751.	716.	589.	757.
SILICA	12.	32.	30.	19.
CALCIUM	110.	99.	77.	110.
MAGNESIUM	31.	26.	20.	28.
POTASSIUM	6.7	7.4	6.4	7.5
SODIUM	17.	21.	17.	23.
FLUORIDE	0.2	0.2	0.2	0.2
BICARBONATE	337.	392.	340.	423.
CARBONATE	0.	0.	0.	0.
SULFATE	110.	69.	29.	72.
CHLORIDE	22.	3.7	3.9	2.4
NITRATE	1.0	2.0	1.	1.1
BORON	0.06	0.08	0.07	0.07
IRON	0.37	0.65	0.14	0.46
MANGANESE	0.92	0.89	0.68	0.89
SAR	0.4	0.5	0.5	0.5
TDS	477.	455.	352.	473.
ION BALANCE	2.8%	1.17%	0.63%	2.57%
SAMPLED	bailed	pumped	pumped	bailed
REMARKS	-	-	-	-

Water Chemistry

USBR-210 WELL # | 130-58-19ADD LOCATION | 18.3-19.5 ft. SCREENED INTERVAL

PARAMETER	DATE 1 5-30-83	DATE 2 11-4-83	DATE 3 2-25-84	DATE 4 4-25-84
FIELD pH	7.0	6.7	6.2	6.7
LAB pH	8.0	8.1	7.8	7.6
FIELD TEMP	6.5	8.4	5.0	6.3
FIELD COND	740.	600.	720.	560.
LAB COND	757.	765.	784.	724.
SILICA	12.	32.	30.	18.
CALCIUM	89.	99.	100.	94.
MAGNESIUM	42.	42.	41.	36.
POTASSIUM	4.9	4.8	5.1	5.0
SODIUM	12.	13.	12.	14.
FLUORIDE	0.2	0.2	0.2	0.2
BICARBONATE	474.	488.	512.	458.
CARBONATE	0.	0.	0.	0.
SULFATE	33.	30.	30.	26.
CHLORIDE	7.3	1.8	4.1	1.1
NITRATE	1.	1.	1.	1.
BORON	0.07	0.06	0.06	0.04
IRON	0.38	0.81	0.05	0.36
MANGANESE	0.48	0.59	0.52	0.50
SAR	0.3	0.3	0.3	0.3
TDS	435.	465.	476.	422.
ION BALANCE	0.9%	2.14%	0.83%	1.70%
SAMPLED	bailed	pumped	pumped	bailed
REMARKS	-	-	-	-

Water Chemistry

USBR-207 WELL # | 130-58-19BBB LOCATION | 18.8-20.0 ft. SCREENED INTERVAL

PARAMETER	DATE 1 5-30-83	DATE 2 11-4-83	DATE 3 2-25-84	DATE 4 4-26-84
FIELD pH	7.1	6.8	6.3	6.6
LAB pH	8.0	7.8	7.5	8.4
FIELD TEMP	7.0	8.0	5.5	6.6
FIELD COND	720.	520.	660.	480.
LAB COND	627.	618.	621.	616.
SILICA	26.	31.	32.	26.
CALCIUM	90.	94.	96.	92.
MAGNESIUM	24.	23.	23.	22.
POTASSIUM	4.7	3.1	3.3	3.0
SODIUM	10.	7.5	8.0	9.0
FLUORIDE	0.2	0.2	0.2	0.2
BICARBONATE	393.	386.	393.	375.
CARBONATE	0.	0.	0.	6.
SULFATE	28.	24.	16.	20.
CHLORIDE	10.	1.8	1.4	1.8
NITRATE	1.	1.	1.	0.0
BORON	0.03	0.05	0.04	0.04
IRON	1.8	3.2	2.2	3.1
MANGANESE	1.4	1.4	1.4	1.3
SAR	0.2	0.2	0.2	0.2
TDS	391.	380.	379.	369.
ION BALANCE	2.16%	0.58%	1.94%	0.29%
SAMPLED	bailed	pumped	pumped	bailed
REMARKS	-	-	rust	-

Water Chemistry

USBR-198A	130-59-1CCC1	26.3-27.3 ft.
WELL #	LOCATION	SCREENED INTERVAL

PARAMETER	DATE 1	DATE 2	DATE 3	DATE 4
	9-4-83	10-29-83	2-23-84	4-19-84
FIELD pH	7.0	7.2	5.9	6.9
LAB pH	7.8	8.0	8.1	7.6
FIELD TEMP	7.9	7.2	6.9	7.8
FIELD COND	5600.	4800.	4100.	1620.
LAB COND	9530.	9540.	9550.	9550.
SILICA	28.	25.	26.	23.
CALCIUM	440.	430.	480.	480.
MAGNESIUM	530.	500.	530.	530.
POTASSIUM	160.	170.	180.	150.
SODIUM	1500.	1400.	1500.	1400.
FLUORIDE	0.2	0.1	0.2	0.2
BICARBONATE	1180.	1140.	1190.	1170.
CARBONATE	0.	0.	0.	0.
SULFATE	6000.	5600.	5700.	5700.
CHLORIDE	88.	90.	89.	90.
NITRATE	1.	0.3	1.0	3.4
BORON	0.35	0.68	0.61	0.81
IRON	8.4	9.6	8.0	13.
MANGANESE	0.58	0.58	0.60	0.60
SAR	11.	11.	11.	10.
TDS	9300.	8790.	9100.	8970.
ION BALANCE	4.21%	3.76%	1.19%	2.99%
SAMPLED	pumped	pumped	pumped	bailed
REMARKS	rust	rust	rust	rust H2S odor

Water Chemistry

USBR-198B	130-59-1CCC2	16.4-17.6 ft.
WELL #	LOCATION	SCREENED INTERVAL

PARAMETER	DATE 1	DATE 2	DATE 3	DATE 4
	9-4-83	10-29-83	2-23-84	4-19-84
FIELD pH	6.8	7.2	5.7	7.2
LAB pH	7.6	8.0	7.8	7.7
FIELD TEMP	8.4	9.0	6.5	6.7
FIELD COND	4200.	3600.	3400.	1560.
LAB COND	7330.	7450.	7460.	7520.
SILICA	29.	28.	28.	24.
CALCIUM	450.	330	490.	510.
MAGNESIUM	430.	290.	440.	460.
POTASSIUM	140.	160.	160.	150.
SODIUM	920.	1200.	1000.	960.
FLUORIDE	0.2	0.2	0.2	0.2
BICARBONATE	1060.	1120.	1250.	1300.
CARBONATE	0.	0.	0.	0.
SULFATE	4200.	4200.	4100.	4200.
CHLORIDE	66.	66.	67.	67.
NITRATE	1.	1.	0.2	2.7
BORON	0.44	0.58	0.53	0.07
IRON	4.4	9.7	8.7	14.
MANGANESE	0.77	0.67	0.73	0.69
SAR	7.4	12.	7.9	7.4
TDS	6760.	6840.	6911.	7030.
ION BALANCE	2.5%	5.42%	0.22%	0.82%
SAMPLED	pumped	bailed	pumped	bailed
REMARKS	rust	rust	rust	rust H2S odor

Water Chemistry

SWC-12286	130-59-1CCC3	4.1-9.1 ft.
WELL #	LOCATION	SCREENED INTERVAL

PARAMETER	DATE 1	DATE 2	DATE 3	DATE 4
	-	11-5-83	2-23-84	4-19-84
FIELD pH	-	7.1	6.2	7.4
LAB pH	-	7.7	8.2	7.8
FIELD TEMP	-	10.4	3.2	5.5
FIELD COND	-	1550.	1740.	970.
LAB COND	-	2950.	3020.	1750.
SILICA	-	35.	27.	22.
CALCIUM	-	130.	120.	65.
MAGNESIUM	-	160.	170.	80.
POTASSIUM	-	86.	77.	30.
SODIUM	-	360.	350.	220.
FLUORIDE	-	0.3	0.2	0.5
BICARBONATE	-	805.	852.	550.
CARBONATE	-	0.	0.	0.
SULFATE	-	1100.	1100.	530.
CHLORIDE	-	28.	28.	13.
NITRATE	-	3.5	1.0	1.3
BORON	-	0.46	0.38	0.35
IRON	-	3.4	0.63	1.9
MANGANESE	-	0.49	0.38	0.30
SAR	-	5.0	4.8	4.3
TDS	-	2300.	2290.	1240.
ION BALANCE	-	0.74%	0.68%	0.73%
SAMPLED	-	bailed	bailed	bailed
REMARKS	-	-	rust	H2S odor

Water Chemistry

SWC-12297	130-59-1CCC4	59.0-60.0 ft.
WELL #	LOCATION	SCREENED INTERVAL

PARAMETER	DATE 1 9-4-83	DATE 2 10-29-83	DATE 3 2-23-84	DATE 4 4-19-84
FIELD pH	7.1	6.9	5.9	7.1
LAB pH	8.2	8.1	8.0	7.6
FIELD TEMP	9.7	7.9	7.4	7.8
FIELD COND	6800.	6000.	5200.	1730.
LAB COND	13,100.	13,100.	13,100.	13,100.
SILICA	26.	26.	27.	18.
CALCIUM	380.	250.	390.	390.
MAGNESIUM	920.	540.	920.	950.
POTASSIUM	56.	69.	76.	86.
SODIUM	2200.	2900.	2300.	2200.
FLUORIDE	0.2	0.2	0.2	0.2
BICARBONATE	718.	742.	776.	775.
CARBONATE	0.	0.	0.	0.
SULFATE	8700.	9000.	8900.	8900.
CHLORIDE	190.	190.	200.	190.
NITRATE	1.	0.5	1.	14.
BORON	0.50	0.41	0.70	0.58
IRON	0.28	5.0	3.8	4.7
MANGANESE	0.53	0.58	0.67	0.80
SAR	14.	24.	14.	14.
TDS	12,800.	13,300.	13,200.	13,100.
ION BALANCE	1.67%	5.16%	1.64%	2.03%
SAMPLED	pumped	pumped	pumped	bailed
REMARKS	rust	rust H2S odor	H2S odor	rust H2S odor

Water Chemistry

SWC-12298 WELL #	130-59-1CCD1 LOCATION	53.2-54.2 ft. SCREENED INTERVAL

PARAMETER	DATE 1 9-4-83	DATE 2 10-30-83	DATE 3 2-23-84	DATE 4 4-19-84
FIELD pH	6.4	6.9	6.1	6.9
LAB pH	7.8	7.9	7.9	7.5
FIELD TEMP	8.0	7.2	6.6	7.6
FIELD COND	6600.	4600.	3800.	1800.
LAB COND	12,400.	12,500.	12,600.	12,600.
SILICA	26.	26.	25.	21.
CALCIUM	430.	660.	430.	420.
MAGNESIUM	900.	900.	900.	850.
POTASSIUM	170.	170.	190.	160.
SODIUM	2000.	2000.	2100.	2000.
FLUORIDE	0.2	0.2	0.2	0.1
BICARBONATE	995.	1010.	1020.	1010.
CARBONATE	0.	0.	0.	0.
SULFATE	8500.	8400.	8300.	8200.
CHLORIDE	97.	98.	100.	98.
NITRATE	1.0	0.5	1.0	0.7
BORON	0.55	0.66	0.57	0.76
IRON	8.5	8.9	11.0	12.
MANGANESE	0.80	0.75	0.80	0.70
SAR	13.0	12.0	13.0	13.
TDS	12,600.	12,800.	12,600.	12,300.
ION BALANCE	2.41%	1.04%	0.18%	2.17%
SAMPLED	pumped	pumped	pumped	bailed
REMARKS	hvy. rust	rust H2S odor	rust	H2S odor

Water Chemistry

SWC-12299 WELL # | 130-59-1CCD2 LOCATION | 29.2-30.2 ft. SCREENED INTERVAL

PARAMETER	DATE 1 9-4-83	DATE 2 10-30-83	DATE 3 2-23-84	DATE 4 4-19-84
FIELD pH	6.7	7.2	5.8	6.9
LAB pH	7.7	8.0	7.8	7.8
FIELD TEMP	7.8	7.0	6.7	7.6
FIELD COND	5800.	4600.	3100.	1660.
LAB COND	11,300.	11,300.	11,300.	11,100.
SILICA	26.	26.	26.	23.
CALCIUM	510.	620.	510.	500.
MAGNESIUM	820.	810.	810.	790.
POTASSIUM	160.	160.	170.	170.
SODIUM	1700.	1700.	1700.	1700.
FLUORIDE	0.2	0.1	0.1	0.1
BICARBONATE	1020.	1020.	1060.	1050.
CARBONATE	0.	0.	0.	0.
SULFATE	7600.	7600.	7500.	7400.
CHLORIDE	84.	83.	86.	80.
NITRATE	1.	0.4	1.	0.5
BORON	0.50	0.49	0.61	0.63
IRON	12.	11.	11.	17.
MANGANESE	1.6	1.3	1.5	1.5
SAR	11.0	11.	11.	11.
TDS	11,400.	11,500.	11,300.	11,200.
ION BALANCE	1.84%	1.63%	1.62%	1.56%
SAMPLED	pumped	pumped	pumped	bailed
REMARKS	hvy. rust	hvy. rust H2S odor	rust	pH rose fast H2S odor

Water Chemistry

SWC-12300 WELL # | 130-59-1CCD3 LOCATION | 5.3-10.3 ft. SCREENED INTERVAL

PARAMETER	DATE 1 9-4-83	DATE 2 11-5-83	DATE 3 2-23-84	DATE 4 4-19-84
FIELD pH	7.0	7.3	6.7	7.5
LAB pH	7.9	7.7	8.0	7.9
FIELD TEMP	14.8	10.1	3.6	5.9
FIELD COND	800.	610.	780.	710.
LAB COND	749.	825.	559.	863.
SILICA	39.	39.	31.	24.
CALCIUM	57.	61.	41.	58.
MAGNESIUM	27.	30.	21.	33.
POTASSIUM	37.	38.	26.	34.
SODIUM	41.	41.	46.	73.
FLUORIDE	0.2	0.2	0.2	0.1
BICARBONATE	244.	344.	262.	235.
CARBONATE	0.	0.	0.	0.
SULFATE	160.	130.	69.	240.
CHLORIDE	10.	6.8	6.0	3.7
NITRATE	4.2	14.	0.5	9.2
BORON	0.13	0.12	0.09	0.10
IRON	0.28	0.05	0.	0.14
MANGANESE	0.37	0.47	0.36	0.37
SAR	1.1	1.1	1.4	1.9
TDS	496.	530.	370.	592.
ION BALANCE	0.64%	3.05%	4.28%	2.88%
SAMPLED	air lift	bailed	bailed	bailed
REMARKS	-	-	-	-

Water Chemistry

SWC-11920	130-59-1CDD1	80-83 ft.
WELL #	LOCATION	SCREENED INTERVAL

PARAMETER	DATE 1 9-4-83	DATE 2 10-30-83	DATE 3 2-23-84	DATE 4 4-23-84
FIELD pH	6.4	7.5	6.4	7.2
LAB pH	7.9	8.1	7.2	7.6
FIELD TEMP	8.5	7.4	6.8	8.6
FIELD COND	3000.	2300.	2700.	1310.
LAB COND	4110.	4060.	4250.	4240.
SILICA	30.	26.	26.	22.
CALCIUM	220.	210.	220.	240.
MAGNESIUM	73.	71.	94.	75.
POTASSIUM	24.	24.	33.	5.0
SODIUM	650.	630.	680.	670.
FLUORIDE	0.2	0.2	0.2	0.3
BICARBONATE	376.	329.	385.	363.
CARBONATE	0.	0.	0.	0.
SULFATE	1800.	1700.	2000.	1900.
CHLORIDE	200.	200.	200.	200.
NITRATE	1.	1.	1.0	11.
BORON	0.91	0.89	1.1	1.3
IRON	1.6	1.6	2.2	2.1
MANGANESE	0.59	0.60	0.57	0.60
SAR	9.7	9.6	9.7	9.6
TDS	3190.	3030.	3450.	3310.
ION BALANCE	3.61%	2.32%	4.37%	3.96%
SAMPLED	air lift	air lift	bailed	bailed
REMARKS	lt. rust	lt. rust	-	-

Water Chemistry

SWC-11920A — WELL # | 130-59-1CDD2 — LOCATION | 20-25 ft. — SCREENED INTERVAL

PARAMETER	DATE 1 9-4-83	DATE 2 10-30-83	DATE 3 2-23-84	DATE 4 4-23-84
FIELD pH	6.5	7.3	6.3	6.9
LAB pH	7.9	8.3	7.7	8.1
FIELD TEMP	7.8	8.4	6.9	8.4
FIELD COND	5000.	3400.	3100.	1540.
LAB COND	8900.	8890.	8710.	9080.
SILICA	29.	26.	28.	27.
CALCIUM	260.	310.	250.	260.
MAGNESIUM	630.	630.	610.	640.
POTASSIUM	140.	140.	150.	160.
SODIUM	1300.	1400.	1400.	1400.
FLUORIDE	0.2	0.2	0.2	0.2
BICARBONATE	842.	834.	838.	857.
CARBONATE	0.	0.	0.	0.
SULFATE	5700.	5600.	5400.	5600.
CHLORIDE	29.	28.	29.	28.
NITRATE	1.	4.4	1.	0.5
BORON	0.35	0.32	0.68	0.58
IRON	7.0	6.3	3.8	5.9
MANGANESE	0.40	0.37	0.50	0.40
SAR	10.0	10.	11.	11.
TDS	8510.	8560.	8290.	8540.
ION BALANCE	3.25%	0.24%	0.15%	0.32%
SAMPLED	air lift	air lift	bailed	bailed
REMARKS	rust	rust	-	-

Water Chemistry

SWC-12287 WELL # | 130-59-1CDD3 LOCATION | 5.3-11.3 ft. SCREENED INTERVAL

PARAMETER	DATE 1 9-4-83	DATE 2 11-6-83	DATE 3 2-23-84	DATE 4 4-23-84
FIELD pH	6.7	7.1	6.7	7.1
LAB pH	8.0	7.6	7.6	7.4
FIELD TEMP	16.3	10.5	4.7	6.3
FIELD COND	4800.	3300.	3600.	1370.
LAB COND	7280.	7510.	7460.	7230.
SILICA	31.	29.	27.	20.
CALCIUM	190.	250.	180.	190.
MAGNESIUM	460.	510.	480.	450.
POTASSIUM	140.	160.	140.	120.
SODIUM	1100.	1300.	1200.	1100.
FLUORIDE	0.2	0.2	0.2	0.2
BICARBONATE	734.	749.	740.	729.
CARBONATE	0.	0.	0.	0.
SULFATE	4300.	4300.	4300.	4100.
CHLORIDE	20.	22.	20.	16.
NITRATE	1.	0.5	1.0	3.0
BORON	0.46	0.59	0.50	0.43
IRON	1.8	6.0	1.8	3.2
MANGANESE	0.52	1.2	0.34	0.40
SAR	9.8	11.	11.	10.
TDS	6600.	6950.	6700.	6360.
ION BALANCE	1.69%	5.80%	0.89%	0.20%
SAMPLED	air lift	bailed	bailed	bailed
REMARKS	rust H2S odor	H2S odor	diesel odor	H2S odor

Water Chemistry

SWC-12293	130-59-1CDD4	59.1-60.1 ft.
WELL #	LOCATION	SCREENED INTERVAL

PARAMETER	DATE 1	DATE 2	DATE 3	DATE 4
	9-4-83	10-30-83	2-23-84	4-23-84
FIELD pH	6.9	7.2	6.3	7.1
LAB pH	7.9	8.3	7.7	7.4
FIELD TEMP	15.0	8.6	6.2	7.4
FIELD COND	4900.	3600.	3100.	1520.
LAB COND	8910.	8430.	8440.	8750.
SILICA	36.	27.	24.	20.
CALCIUM	410.	290.	470.	450.
MAGNESIUM	460.	230.	330.	390.
POTASSIUM	55.	58.	63.	45.
SODIUM	1400.	1800.	1400.	1500.
FLUORIDE	0.2	0.1	0.1	0.1
BICARBONATE	493.	375.	415.	467.
CARBONATE	0.	0.	0.	0.
SULFATE	5800.	5100.	5200.	5500.
CHLORIDE	98.	97.	100.	98.
NITRATE	1.	0.9	1.0	1.0
BORON	0.44	0.37	0.63	0.76
IRON	0.07	1.2	1.4	1.7
MANGANESE	0.56	0.32	0.47	0.50
SAR	11.	19.	12.	12.6
TDS	8500.	7790.	7790.	8240.
ION BALANCE	4.37%	0.84%	2.08%	1.63%
SAMPLED	pumped	pumped	pumped	bailed
REMARKS	-	-	rust	-

Water Chemistry

USBR-199A — WELL # | 130-59-1DDD1 — LOCATION | 29.2-30.4 ft. — SCREENED INTERVAL

PARAMETER	DATE 1 9-3-83	DATE 2 10-30-83	DATE 3 2-24-84	DATE 4 4-19-84
FIELD pH	6.7	6.8	6.4	6.8
LAB pH	8.0	8.1	7.9	7.6
FIELD TEMP	11.2	8.7	7.8	7.8
FIELD COND	890.	770.	940.	700.
LAB COND	983.	978.	1110.	1090.
SILICA	26.	28.	29.	27.
CALCIUM	97.	120.	120.	130.
MAGNESIUM	46.	54.	49.	48.
POTASSIUM	11.	12.	10.	9.5
SODIUM	55.	55.	53.	54.
FLUORIDE	0.2	0.2	0.2	0.2
BICARBONATE	425.	391.	403.	496.
CARBONATE	0.	0.	0.	0.
SULFATE	210.	220.	220.	210.
CHLORIDE	3.5	5.1	3.0	1.4
NITRATE	1.	1.	1.	1.
BORON	0.10	0.10	0.18	0.15
IRON	1.8	2.3	1.1	2.
MANGANESE	0.55	0.64	0.70	0.63
SAR	1.2	1.1	1.0	1.0
TDS	661.	691.	735.	728.
ION BALANCE	0.79%	8.11%	1.33%	1.80%
SAMPLED	cent. pump	pumped	pumped	bailed
REMARKS	-	rust	lt. rust	-

Water Chemistry

USBR-199B	130-59-1DDD2	13.4-14.6 ft.
WELL #	LOCATION	SCREENED INTERVAL

PARAMETER	DATE 1	DATE 2	DATE 3	DATE 4
	9-4-83	11-6-83	2-24-84	4-19-84
FIELD pH	6.6	6.9	6.4	6.8
LAB pH	7.8	7.9	7.5	7.5
FIELD TEMP	12.1	9.0	7.1	6.5
FIELD COND	1240.	1040.	690.	340.
LAB COND	1570.	1670.	1680.	1670.
SILICA	33.	34.	29.	19.
CALCIUM	190.	270.	210.	220.
MAGNESIUM	78.	78.	74.	75.
POTASSIUM	13.	14.	12.	12.
SODIUM	83.	83.	82.	80.
FLUORIDE	0.2	0.2	0.2	0.2
BICARBONATE	378.	483.	487.	480.
CARBONATE	0.	0.	0.	0.
SULFATE	620.	610.	600.	600.
CHLORIDE	3.8	3.5	3.0	4.8
NITRATE	1.0	3.1	1.0	1.
BORON	0.10	0.13	0.10	0.13
IRON	1.4	0.26	0.21	0.60
MANGANESE	0.81	0.82	0.83	1.0
SAR	1.3	1.1	1.2	1.2
TDS	1210.	1340.	1250.	1250.
ION BALANCE	1.51%	6.9%	0.32%	0.99%
SAMPLED	cent. pump	bailed	pumped	bailed
REMARKS	-	-	-	-

Water Chemistry

SWC-12291	130-59-1DDD3	59.2-60.2 ft.
WELL #	LOCATION	SCREENED INTERVAL

PARAMETER	DATE 1	DATE 2	DATE 3	DATE 4
	9-4-83	10-30-83	2-24-84	4-19-84
FIELD pH	6.9	6.8	6.7	6.8
LAB pH	7.8	8.0	7.9	7.4
FIELD TEMP	17.1	9.2	7.0	8.2
FIELD COND	2700.	2500.	2300.	940.
LAB COND	4620.	6180.	6190.	6130.
SILICA	28.	27.	25.	19.
CALCIUM	410.	730.	600.	600.
MAGNESIUM	250.	330.	320.	320.
POTASSIUM	35.	34.	35.	46.
SODIUM	470.	800.	750.	720.
FLUORIDE	0.2	0.1	0.1	0.2
BICARBONATE	508.	532.	605.	577.
CARBONATE	0.	0.	0.	0.
SULFATE	2700.	3900.	3800.	3800.
CHLORIDE	18.	27.	28.	27.
NITRATE	1.	1.	1.	1.
BORON	0.30	0.39	0.41	0.50
IRON	0.96	6.4	4.2	5.6
MANGANESE	1.2	1.5	1.7	1.8
SAR	4.5	6.2	6.2	5.9
TDS	4200.	6120.	5860.	5830.
ION BALANCE	2.12%	4.50%	0.03%	0.34%
SAMPLED	cent. pump	pumped	pumped	bailed
REMARKS	mud	turbid	rust	-

Water Chemistry

SWC-12292	130-59-1DDD4	39.2-41.2 ft.
WELL #	LOCATION	SCREENED INTERVAL

PARAMETER	DATE 1	DATE 2	DATE 3	DATE 4
	9-4-83	10-30-83	2-24-84	4-19-84
FIELD pH	6.7	7.1	6.6	6.8
LAB pH	7.8	8.2	7.8	7.5
FIELD TEMP	16.9	8.6	7.1	7.9
FIELD COND	2100.	1480.	1440.	1020.
LAB COND	3200.	3090.	3090.	3760.
SILICA	29.	28.	27.	20.
CALCIUM	200.	250.	200.	240.
MAGNESIUM	250.	260.	230.	280.
POTASSIUM	17.	16.	17.	21.
SODIUM	240.	240.	250.	360.
FLUORIDE	0.2	0.2	0.2	0.2
BICARBONATE	529.	527.	556.	560.
CARBONATE	0.	0.	0.	0.
SULFATE	1700.	1600.	1500.	2000.
CHLORIDE	7.4	5.9	6.0	9.9
NITRATE	1.	0.3	1.0	1.
BORON	0.14	0.10	0.17	0.17
IRON	6.3	0.03	4.7	5.6
MANGANESE	1.3	0.88	1.2	1.4
SAR	2.7	2.5	2.9	3.7
TDS	2710.	2660.	2510.	3220.
ION BALANCE	3.36%	2.98%	0.41%	0.08%
SAMPLED	cent. pump	pumped	pumped	bailed
REMARKS	rust	rust H2S odor	rust	rust H2S odor

Water Chemistry

USGS WELL #		130-59-2AAA LOCATION		- SCREENED INTERVAL
PARAMETER	DATE 1 6-1-83	DATE 2 10-30-83	DATE 3 -	DATE 4 -
FIELD pH	7.1	6.9	-	-
LAB pH	7.8	8.0	-	-
FIELD TEMP	6.2	8.4	-	-
FIELD COND	660.	640.	-	-
LAB COND	786.	679.	-	-
SILICA	26.	28.	-	-
CALCIUM	98.	100.	-	-
MAGNESIUM	35.	34.	-	-
POTASSIUM	11.	13.	-	-
SODIUM	15.	17.	-	-
FLUORIDE	0.1	0.1	-	-
BICARBONATE	483.	408.	-	-
CARBONATE	0.	0.	-	-
SULFATE	32.	38.	-	-
CHLORIDE	12.	8.3	-	-
NITRATE	1.	1.	-	-
BORON	0.05	0.03	-	-
IRON	1.6	2.0	-	-
MANGANESE	1.0	1.0	-	-
SAR	0.3	0.4	-	-
TDS	471.	443.	-	-
ION BALANCE	1.5%	6.75%	-	-
SAMPLED	bailed	pumped	-	-
REMARKS	-	rust	-	-

Water Chemistry

Ronney Irrigation WELL # | 130-59-2BAA LOCATION | - SCREENED INTERVAL

PARAMETER	DATE 1	DATE 2	DATE 3	DATE 4
	6-2-83	9-3-83	-	-
FIELD pH	7.1	6.6	-	-
LAB pH	7.9	7.1	-	-
FIELD TEMP	9.2	11.2	-	-
FIELD COND	840.	830.	-	-
LAB COND	738.	739.	-	-
SILICA	25.	21.	-	-
CALCIUM	100.	100.	-	-
MAGNESIUM	37.	30.	-	-
POTASSIUM	4.2	5.8	-	-
SODIUM	14.	22.	-	-
FLUORIDE	0.2	0.2	-	-
BICARBONATE	308.	342.	-	-
CARBONATE	0.	0.	-	-
SULFATE	160.	130.	-	-
CHLORIDE	9.7	7.1	-	-
NITRATE	1.	*1.	-	-
BORON	0.07	0.04	-	-
IRON	2.3	2.5	-	-
MANGANESE	1.6	0.79	-	-
SAR	0.3	0.5	-	-
TDS	507.	488.	-	-
ION BALANCE	0.40%	0.12%	-	-
SAMPLED	bailed	bailed	-	-
REMARKS	-	-	-	-

Water Chemistry

Ronney Irrigation WELL # | 130-59-2BAA2 LOCATION | - SCREENED INTERVAL

PARAMETER	DATE 1	DATE 2	DATE 3	DATE 4
	6-2-83	9-3-83	-	-
FIELD pH	7.1	7.2	-	-
LAB pH	7.9	7.8	-	-
FIELD TEMP	8.5	10.7	-	-
FIELD COND	1210.	1490.	-	-
LAB COND	1430.	1700.	-	-
SILICA	28.	32.	-	-
CALCIUM	190.	250.	-	-
MAGNESIUM	66.	80.	-	-
POTASSIUM	7.8	9.5	-	-
SODIUM	35.	36.	-	-
FLUORIDE	0.2	0.2	-	-
BICARBONATE	328.	328.	-	-
CARBONATE	0.	0.	-	-
SULFATE	560.	790.	-	-
CHLORIDE	15.	6.1	-	-
NITRATE	0.	1.	-	-
BORON	0.07	0.06	-	-
IRON	0.42	1.4	-	-
MANGANESE	1.5	1.8	-	-
SAR	0.6	0.5	-	-
TDS	1070.	1370.	-	-
ION BALANCE	2.46%	2.7%	-	-
SAMPLED	bailed	pumped	-	-
REMARKS	-	-	-	-

Water Chemistry

Ronney Irrigation WELL # | 130-59-2Bcenter LOCATION | - SCREENED INTERVAL

PARAMETER	DATE 1 6-2-83	DATE 2 9-3-83	DATE 3 -	DATE 4 -
FIELD pH	7.1	6.8	-	-
LAB pH	8.0	7.8	-	-
FIELD TEMP	8.0	12.5	-	-
FIELD COND	1690.	1630.	-	-
LAB COND	1790.	1880.	-	-
SILICA	7.8	16.	-	-
CALCIUM	310.	220.	-	-
MAGNESIUM	98.	95.	-	-
POTASSIUM	11.	11.	-	-
SODIUM	80.	90.	-	-
FLUORIDE	0.2	0.2	-	-
BICARBONATE	205.	344.	-	-
CARBONATE	0.	0.	-	-
SULFATE	880.	860.	-	-
CHLORIDE	24.	21.	-	-
NITRATE	1.	1.	-	-
BORON	0.10	0.06	-	-
IRON	6.7	0.56	-	-
MANGANESE	1.6	1.0	-	-
SAR	1.0	1.3	-	-
TDS	1520.	1480.	-	-
ION BALANCE	9.86%	2.48%	-	-
SAMPLED	bailed	bailed	-	-
REMARKS	-	-	-	-

Water Chemistry

USBR-133 WELL # | 130-59-2BBB LOCATION | - SCREENED INTERVAL

PARAMETER	DATE 1	DATE 2	DATE 3	DATE 4
	6-1-83	10-28-83	-	-
FIELD pH	7.8	7.5	-	-
LAB pH	7.9	8.1	-	-
FIELD TEMP	8.0	9.2	-	-
FIELD COND	720.	675.	-	-
LAB COND	764.	671.	-	-
SILICA	12.	27.	-	-
CALCIUM	82.	74.	-	-
MAGNESIUM	41.	37.	-	-
POTASSIUM	3.9	3.4	-	-
SODIUM	22.	23.	-	-
FLUORIDE	0.4	0.6	-	-
BICARBONATE	389.	350.	-	-
CARBONATE	0.	0.	-	-
SULFATE	110.	77.	-	-
CHLORIDE	10.	6.2	-	-
NITRATE	1.	5.6	-	-
BORON	0.07	0.06	-	-
IRON	0.02	0.02	-	-
MANGANESE	0.38	0.23	-	-
SAR	0.5	0.5	-	-
TDS	475.	426.	-	-
ION BALANCE	2.7%	1.23%	-	-
SAMPLED	bailed	pumped	-	-
REMARKS	-	-	-	-

Water Chemistry

SWC-12282	130-59-2BBB1	36.0-37.0 ft.
WELL #	LOCATION	SCREENED INTERVAL

PARAMETER	DATE 1 9-3-83	DATE 2 10-28-83	DATE 3 2-19-84	DATE 4 4-24-84
FIELD pH	6.6	7.5	6.3	6.7
LAB pH	7.7	8.0	7.4	7.4
FIELD TEMP	9.6	8.2	6.0	8.2
FIELD COND	2100.	1780.	-	600.
LAB COND	2520.	2640.	2680.	2740.
SILICA	30.	27.	29.	25.
CALCIUM	520.	550.	450.	470.
MAGNESIUM	120.	120.	120.	120.
POTASSIUM	13.	13.	13.	13.
SODIUM	70.	73.	74.	72.
FLUORIDE	0.2	0.2	0.2	0.2
BICARBONATE	330.	330.	348.	346.
CARBONATE	0.	0.	0.	0.
SULFATE	1400.	1400.	1400.	1500.
CHLORIDE	46.	47.	50.	52.
NITRATE	1.	3.5	1.	0.3
BORON	0.	0.09	0.08	0.17
IRON	3.9	4.6	3.4	4.8
MANGANESE	2.5	2.6	2.5	2.5
SAR	0.7	0.7	0.8	0.8
TDS	2370.	2400.	2310.	2430.
ION BALANCE	4.41%	6.34%	0.57%	2.13%
SAMPLED	pumped	pumped	bailed	bailed
REMARKS	-	rust	H2S odor	H2S odor

Water Chemistry

SWC-12283	130-59-2BBB2	11.25-15.25 ft.
WELL #	LOCATION	SCREENED INTERVAL

PARAMETER	DATE 1	DATE 2	DATE 3	DATE 4
	-	10-28-83	2-19-84	4-24-84
FIELD pH	-	7.5	6.3	6.9
LAB pH	-	7.7	7.9	7.7
FIELD TEMP	-	10.1	3.8	7.3
FIELD COND	-	730.	-	440.
LAB COND	-	760.	742.	747.
SILICA	-	28.	27.	24.
CALCIUM	-	87.	91.	83.
MAGNESIUM	-	36.	37.	34.
POTASSIUM	-	5.1	3.5	3.2
SODIUM	-	21.	20.	20.
FLUORIDE	-	0.5	0.3	0.4
BICARBONATE	-	367.	382.	373.
CARBONATE	-	0.	0.	0.
SULFATE	-	79.	78.	89.
CHLORIDE	-	15.	18.	14.
NITRATE	-	10.	1.	2.2
BORON	-	0.08	0.07	0.05
IRON	-	0.09	0.05	0.01
MANGANESE	-	0.01	0.06	0.10
SAR	-	0.5	0.4	0.5
TDS	-	463.	464.	454.
ION BALANCE	-	0.42%	0.71%	3.19%
SAMPLED	-	bailed	bailed	bailed
REMARKS	-	-	-	-

Water Chemistry

SWC-12301	130-59-2BBB3	59.1-60.1 ft.
WELL #	LOCATION	SCREENED INTERVAL

PARAMETER	DATE 1	DATE 2	DATE 3	DATE 4
	9-3-83	10-28-83	2-19-84	4-24-84
FIELD pH	6.8	7.6	6.4	6.9
LAB pH	7.7	7.9	7.5	7.8
FIELD TEMP	11.3	9.3	6.6	8.1
FIELD COND	1870.	1680.	-	800.
LAB COND	2100.	1950.	2000.	2000.
SILICA	32.	28.	30.	28.
CALCIUM	130.	120.	120.	150.
MAGNESIUM	35.	32.	31.	32.
POTASSIUM	25.	20.	21.	20.
SODIUM	290.	280.	260.	290.
FLUORIDE	0.2	0.2	0.2	0.2
BICARBONATE	400.	353.	385.	407.
CARBONATE	0.	0.	0.	0.
SULFATE	560.	490.	460.	480.
CHLORIDE	170.	170.	180.	170.
NITRATE	1.	8.7	1.	1.
BORON	0.59	0.51	0.74	0.88
IRON	0.02	0.36	0.50	0.42
MANGANESE	0.33	0.42	0.45	0.45
SAR	5.8	5.9	5.5	5.6
TDS	1400.	1320.	1290.	1370.
ION BALANCE	0.90%	0.90%	1.47%	3.96%
SAMPLED	air lift	pumped	bailed	bailed
REMARKS	-	-	H2S odor	H2S odor

Water Chemistry

SWC-12280	130-59-2BCB1	26.7-27.7 ft.
WELL #	LOCATION	SCREENED INTERVAL

PARAMETER	DATE 1 9-3-83	DATE 2 10-28-83	DATE 3 2-19-84	DATE 4 4-24-84
FIELD pH	6.4	7.2	6.6	6.9
LAB pH	7.8	7.9	7.5	7.5
FIELD TEMP	9.9	7.6	6.2	7.6
FIELD COND	4600.	4200.	-	960.
LAB COND	6420.	6520.	6560.	6380.
SILICA	30.	25.	30.	26.
CALCIUM	470.	340.	380.	370.
MAGNESIUM	430.	390.	410.	410.
POTASSIUM	28.	26.	36.	34.
SODIUM	810.	730.	720.	760.
FLUORIDE	0.2	0.2	0.2	0.2
BICARBONATE	636.	635.	706.	706.
CARBONATE	0.	0.	0.	0.
SULFATE	3400.	3200.	3000.	3100.
CHLORIDE	430.	450.	460.	440.
NITRATE	1.	7.5	1.	1.
BORON	0.02	0.15	8.13	0.10
IRON	6.3	7.4	4.7	7.8
MANGANESE	1.4	1.4	1.3	1.3
SAR	6.5	6.4	6.7	6.5
TDS	5920.	5490.	5360.	5500.
ION BALANCE	0.75%	4.89%	0.54%	1.39%
SAMPLED	pumped	pumped	bailed	bailed
REMARKS	-	rust	-	H2S odor

Water Chemistry

SWC-12281 WELL # | 130-59-2BCB2 LOCATION | 12.7-14.7 ft. SCREENED INTERVAL

PARAMETER	DATE 1 9-3-83	DATE 2 10-28-83	DATE 3 2-19-84	DATE 4 4-24-84
FIELD pH	6.9	7.2	6.9	6.8
LAB pH	7.7	7.9	7.8	7.6
FIELD TEMP	12.5	8.9	4.3	6.8
FIELD COND	960.	840.	-	520.
LAB COND	980.	954.	952.	932.
SILICA	33.	32.	36.	30.
CALCIUM	100.	110.	110.	110.
MAGNESIUM	40.	39.	37.	39.
POTASSIUM	18.	14.	7.9	12.
SODIUM	51.	49.	43.	52.
FLUORIDE	0.3	0.2	0.3	0.2
BICARBONATE	355.	379.	394.	378.
CARBONATE	0.	0.	0.	0.
SULFATE	250.	220.	200.	200.
CHLORIDE	8.3	6.8	7.3	5.8
NITRATE	1.	6.3	1.	0.4
BORON	0.06	0.10	0.07	0.08
IRON	0.12	0.46	0.24	0.69
MANGANESE	0.52	1.2	1.0	0.99
SAR	1.1	1.0	0.9	1.1
TDS	677.	666.	638.	637.
ION BALANCE	1.53%	0.45%	1.26%	3.35%
SAMPLED	air lift	bailed	bailed	bailed
REMARKS	-	org. odor	-	-

Water Chemistry

USBR-142 — WELL # | 130-59-2CBB — LOCATION | - — SCREENED INTERVAL

PARAMETER	DATE 1	DATE 2	DATE 3	DATE 4
	6-1-83	10-29-83	-	-
FIELD pH	7.6	6.8	-	-
LAB pH	7.9	8.3	-	-
FIELD TEMP	7.6	6.9	-	-
FIELD COND	3700.	3700.	-	-
LAB COND	5940.	5970.	-	-
SILICA	27.	27.	-	-
CALCIUM	320.	360.	-	-
MAGNESIUM	410.	400.	-	-
POTASSIUM	27.	25.	-	-
SODIUM	760.	850.	-	-
FLUORIDE	0.3	0.3	-	-
BICARBONATE	571.	593.	-	-
CARBONATE	0.	0.	-	-
SULFATE	3600.	3400.	-	-
CHLORIDE	120.	110.	-	-
NITRATE	1.	3.9	-	-
BORON	0.28	0.17	-	-
IRON	4.4	6.3	-	-
MANGANESE	0.73	0.78	-	-
SAR	6.6	7.4	-	-
TDS	5550.	5480.	-	-
ION BALANCE	2.50%	2.78%	-	-
SAMPLED	bailed	pumped	-	-
REMARKS	-	rust	-	-

Water Chemistry

SWC-12278 WELL # | 130-59-2CBB1 LOCATION | 30.4-31.4 ft. SCREENED INTERVAL

PARAMETER	DATE 1 9-3-83	DATE 2 10-29-83	DATE 3 2-26-84	DATE 4 4-24-84
FIELD pH	7.1	6.7	5.9	6.6
LAB pH	7.9	8.2	8.0	7.5
FIELD TEMP	8.6	6.7	6.2	7.5
FIELD COND	4200.	3600.	1180.	1320.
LAB COND	5840.	5830.	5840.	5830.
SILICA	29.	27.	27.	26.
CALCIUM	250.	330.	260.	270.
MAGNESIUM	350.	360.	330.	340.
POTASSIUM	25.	27.	32.	26.
SODIUM	810.	920.	850.	830.
FLUORIDE	0.3	0.4	0.3	0.5
BICARBONATE	635.	633.	649.	636.
CARBONATE	0.	0.	0.	0.
SULFATE	3300.	3100.	3200.	3200.
CHLORIDE	110.	100.	100.	100.
NITRATE	1.	1.9	1.	1.
BORON	0.09	0.24	0.21	0.23
IRON	4.5	4.8	4.0	4.0
MANGANESE	0.87	0.73	0.76	0.80
SAR	7.7	8.3	8.3	7.9
TDS	5190.	5180.	5130.	5110.
ION BALANCE	3.21%	5.47%	1.39%	1.06%
SAMPLED	pumped	pumped	bailed	bailed
REMARKS	rust	rust	-	H2S odor

Water Chemistry

SWC-12279	130-59-2CBB2	14.1-16.1 ft.
WELL #	LOCATION	SCREENED INTERVAL

PARAMETER	DATE 1	DATE 2	DATE 3	DATE 4
	9-3-83	10-29-83	2-26-84	4-24-84
FIELD pH	7.1	6.7	6.3	6.9
LAB pH	8.3	8.1	8.1	8.0
FIELD TEMP	9.2	7.9	6.2	5.8
FIELD COND	1680.	1490.	710.	600.
LAB COND	1920.	1970.	1790.	911.
SILICA	31.	30.	25.	24.
CALCIUM	54.	56.	52.	28.
MAGNESIUM	42.	43.	44.	38.
POTASSIUM	15.	15.	15.	8.2
SODIUM	350.	350.	310.	130.
FLUORIDE	0.4	0.5	0.4	0.5
BICARBONATE	573.	576.	565.	430.
CARBONATE	0.	0.	0.	0.
SULFATE	590.	570.	470.	140.
CHLORIDE	21.	20.	18.	3.8
NITRATE	1.	1.	0.4	1.
BORON	0.09	0.10	0.11	0.12
IRON	0.45	1.4	1.1	0.53
MANGANESE	0.49	0.49	0.45	0.16
SAR	8.6	8.5	7.7	3.7
TDS	1390.	1370.	1210.	586.
ION BALANCE	1.25%	0.05%	1.24%	1.36%
SAMPLED	air lift	bailed	bailed	bailed
REMARKS	-	H2S odor	-	-

Water Chemistry

SWC-12302	130-59-2CBB3	58.6-59.6 ft.
WELL #	LOCATION	SCREENED INTERVAL

PARAMETER	DATE 1 9-4-83	DATE 2 10-29-83	DATE 3 2-26-84	DATE 4 4-24-84
FIELD pH	10.3	7.1	6.0	6.6
LAB pH	10.7	7.8	7.8	7.6
FIELD TEMP	10.5	6.4	6.2	7.8
FIELD COND	2900.	2300.	1220.	1070.
LAB COND	3220.	3100.	3230.	3210.
SILICA	25.	31.	29.	31.
CALCIUM	96.	200.	160.	220.
MAGNESIUM	1.5	21.	43.	50.
POTASSIUM	180.	57.	55.	40.
SODIUM	460.	510.	500.	540.
FLUORIDE	0.2	0.2	0.1	0.1
BICARBONATE	21. .OH-	79.	131.	146.
CARBONATE	25.	0.	0.	0.
SULFATE	1100.	1200.	1300.	1300.
CHLORIDE	220.	230.	240.	240.
NITRATE	1.	8.6	0.5	0.2
BORON	0.28	0.38	0.70	0.50
IRON	0.04	0.03	0.04	0.04
MANGANESE	0.01	0.04	0.02	0.07
SAR	13.	9.1	9.1	8.5
TDS	2130.	2300.	2390.	2490.
ION BALANCE	2.75%	3.59%	1.88%	4.43%
SAMPLED	pumped	pumped	bailed	bailed
REMARKS	slightly turbid	pH rose quickly	-	H2S odor

Water Chemistry

SWC-12276	130-59-2CCB1	36.2-37.2 ft.
WELL #	LOCATION	SCREENED INTERVAL

PARAMETER	DATE 1 9-3-83	DATE 2 10-29-83	DATE 3 2-25-84	DATE 4 4-25-84
FIELD pH	6.6	7.0	6.2	6.2
LAB pH	7.9	8.2	8.1	7.5
FIELD TEMP	8.8	8.1	6.6	7.9
FIELD COND	2300.	2000.	1590.	1030.
LAB COND	3090.	3100.	3080.	3080.
SILICA	30.	27.	27.	25.
CALCIUM	210.	260.	210.	280.
MAGNESIUM	160.	160.	150.	150.
POTASSIUM	20.	18.	19.	21.
SODIUM	340.	390.	360.	370.
FLUORIDE	0.1	0.2	0.1	0.1
BICARBONATE	891.	925.	970.	972.
CARBONATE	0.	0.	0.	0.
SULFATE	1100.	1100.	1000.	1100.
CHLORIDE	59.	62.	64.	58.
NITRATE	1.	6.1	1.	4.7
BORON	0.11	0.13	0.11	0.08
IRON	7.5	6.8	8.6	9.5
MANGANESE	1.2	1.1	1.2	1.1
SAR	4.3	4.7	4.7	4.5
TDS	2370.	2490.	2320.	2500.
ION BALANCE	0.32%	4.36%	0.54%	2.86%
SAMPLED	pumped	pumped	pumped	bailed
REMARKS	-	rust	rust	H2S odor

Water Chemistry

SWC-12303	130-59-2CCB3	58.2-59.2 ft.
WELL #	LOCATION	SCREENED INTERVAL

PARAMETER	DATE 1 9-3-83	DATE 2 10-29-83	DATE 3 2-25-84	DATE 4 4-24-84
FIELD pH	6.7	7.0	6.2	6.4
LAB pH	7.8	7.7	8.1	7.4
FIELD TEMP	21.0	8.0	6.3	8.0
FIELD COND	2200.	2200.	1640.	1130.
LAB COND	2470.	2740.	2740.	2970.
SILICA	25.	25.	25.	20.
CALCIUM	130.	140.	140.	160.
MAGNESIUM	47.	40.	40.	48.
POTASSIUM	28.	20.	18.	16.
SODIUM	380.	440.	420.	430.
FLUORIDE	0.3	0.3	0.2	0.2
BICARBONATE	384.	326.	412.	256.
CARBONATE	0.	0.	0.	0.
SULFATE	870.	890.	790.	1100.
CHLORIDE	130.	190.	220.	170.
NITRATE	1.	0.1	0.4	0.7
BORON	0.51	0.72	1.0	0.92
IRON	0.17	0.68	0.63	0.68
MANGANESE	0.77	0.34	0.34	0.40
SAR	7.3	8.5	8.1	7.6
TDS	1800.	1910.	1860.	2070.
ION BALANCE	0.90%	1.15%	0.70%	1.36%
SAMPLED	pumped	pumped	pumped	bailed
REMARKS	-	-	-	H2S odor

Water Chemistry

SWC-12304	130-59-2CCB4	8.4-13.4 ft.
WELL #	LOCATION	SCREENED INTERVAL

PARAMETER	DATE 1 9-3-83	DATE 2 10-29-83	DATE 3 2-25-84	DATE 4 4-25-84
FIELD pH	6.8	6.9	6.3	6.3
LAB pH	7.9	8.0	8.0	8.1
FIELD TEMP	12.2	9.6	4.5	5.5
FIELD COND	1490.	1460.	1260.	730.
LAB COND	1810.	1770.	1800.	1430.
SILICA	32.	29.	25.	22.
CALCIUM	140.	120.	130.	98.
MAGNESIUM	94.	79.	84.	81.
POTASSIUM	16.	15.	15.	13.
SODIUM	170.	190.	180.	110.
FLUORIDE	0.2	0.3	0.2	0.2
BICARBONATE	789.	784.	782.	677.
CARBONATE	0.	0.	0.	0.
SULFATE	440.	400.	400.	260.
CHLORIDE	16.	13.	16.	7.7
NITRATE	1.	4.3	1.	2.9
BORON	0.12	0.12	0.14	0.11
IRON	0.03	1.2	0.60	1.1
MANGANESE	1.4	2.1	1.8	0.94
SAR	2.7	3.3	3.0	2.0
TDS	1200.	1240.	1240.	940.
ION BALANCE	0.09%	1.16%	0.05%	1.30%
SAMPLED	air lift	bailed	bailed	bailed
REMARKS	-	H2S ODOR	-	H2S odor

Water Chemistry

USBR-143 WELL # | 130-59-2CDD LOCATION | - SCREENED INTERVAL

PARAMETER	DATE 1	DATE 2	DATE 3	DATE 4
	5-31-83	10-29-83	-	-
FIELD pH	6.9	7.1	-	-
LAB pH	7.9	8.3	-	-
FIELD TEMP	7.3	9.1	-	-
FIELD COND	1680.	1560.	-	-
LAB COND	2060.	2090.	-	-
SILICA	14.	30.	-	-
CALCIUM	98.	110.	-	-
MAGNESIUM	100.	100.	-	-
POTASSIUM	41.	47.	-	-
SODIUM	230.	240.	-	-
FLUORIDE	0.1	0.1	-	-
BICARBONATE	948.	961.	-	-
CARBONATE	0.	0.	-	-
SULFATE	440.	480.	-	-
CHLORIDE	18.	10.	-	-
NITRATE	9.2	5.8	-	-
BORON	0.18	0.15	-	-
IRON	2.7	5.0	-	-
MANGANESE	0.90	1.1	-	-
SAR	3.9	4.0	-	-
TDS	1420.	1500.	-	-
ION BALANCE	2.4%	1.48%	-	-
SAMPLED	bailed	pumped	-	-
REMARKS	-	rust	-	-

Water Chemistry

SWC-12284 WELL# | 130-59-2CDD1 LOCATION | 38.2-39.2 ft. SCREENED INTERVAL

PARAMETER	DATE 1 9-4-83	DATE 2 10-24-83	DATE 3 2-23-84	DATE 4 4-25-84
FIELD pH	6.7	6.9	6.0	6.5
LAB pH	7.8	7.9	7.8	7.7
FIELD TEMP	9.2	8.4	7.6	7.3
FIELD COND	3200.	2900.	1920.	1000.
LAB COND	5190.	5240.	6070.	5260.
SILICA	29.	25.	26.	24.
CALCIUM	370.	470.	410.	390.
MAGNESIUM	310.	320.	330.	320.
POTASSIUM	48.	49.	57.	54.
SODIUM	550.	610.	600.	560.
FLUORIDE	0.2	0.1	0.2	0.2
BICARBONATE	1090.	1080.	1200.	1170.
CARBONATE	0.	0.	0.	0.
SULFATE	2600.	2700.	2500.	2600.
CHLORIDE	56.	55.	54.	53.
NITRATE	1.	9.1	1.	0.6
BORON	0.18	0.21	0.27	0.31
IRON	15.	14.	15.	18.
MANGANESE	1.4	1.2	1.3	1.2
SAR	5.1	5.3	5.3	5.1
TDS	4520.	4800.	4590.	4600.
ION BALANCE	3.1%	1.27%	1.28%	2.26%
SAMPLED	pumped	pumped	pumped	bailed
REMARKS	rust H2S odor	rust H2S odor	rust -	rust H2S odor

Water Chemistry

SWC-12285	130-59-2CDD2	9.7-17.7 ft.
WELL #	LOCATION	SCREENED INTERVAL

PARAMETER	DATE 1	DATE 2	DATE 3	DATE 4
	9-4-83	11-5-83	2-23-84	4-25-84
FIELD pH	7.1	7.1	6.2	7.1
LAB pH	8.3	8.0	8.2	8.0
FIELD TEMP	9.2	10.2	6.8	6.3
FIELD COND	1280.	920.	1160.	790.
LAB COND	1300.	1200.	1190.	1250.
SILICA	31.	31.	28.	23.
CALCIUM	44.	37.	37.	41.
MAGNESIUM	44.	35.	37.	39.
POTASSIUM	32.	34.	37.	27.
SODIUM	190.	190.	200.	190.
FLUORIDE	0.3	0.4	0.4	0.4
BICARBONATE	724.	686.	686.	701.
CARBONATE	0.	0.	0.	0.
SULFATE	150.	100.	110.	130.
CHLORIDE	2.7	2.1	3.3	1.9
NITRATE	0.3	4.2	1.8	2.7
BORON	0.16	0.19	0.17	0.21
IRON	0.34	1.5	0.06	1.2
MANGANESE	0.42	0.52	0.42	0.50
SAR	4.8	5.3	5.6	5.1
TDS	852.	774.	793.	802.
ION BALANCE	0.60%	1.46%	2.53%	0.31%
SAMPLED	air lift	bailed	bailed	bailed
REMARKS	-	-	-	H2S odor

Water Chemistry

SWC-12294 WELL # | 130-59-2CDD3 LOCATION | 59.0-60.0 ft. SCREENED INTERVAL

PARAMETER	DATE 1 9-4-83	DATE 2 10-29-83	DATE 3 2-23-84	DATE 4 4-25-84
FIELD pH	7.1	6.9	6.1	6.9
LAB pH	7.6	7.8	7.8	7.3
FIELD TEMP	9.5	8.8	7.1	7.6
FIELD COND	3200.	2300.	1830.	1240.
LAB COND	4200.	3930.	3860.	3870.
SILICA	27.	23.	23.	22.
CALCIUM	330.	240.	350.	360.
MAGNESIUM	130.	92.	120.	120.
POTASSIUM	89.	30.	31.	27.
SODIUM	500.	630.	470.	460.
FLUORIDE	0.2	0.2	0.2	0.2
BICARBONATE	569.	609.	626.	631.
CARBONATE	0.	0.	0.	0.
SULFATE	2100.	1800.	1600.	1800.
CHLORIDE	100.	110.	110.	110.
NITRATE	1.	0.7	1.	1.
BORON	0.41	0.47	0.18	0.62
IRON	0.04	4.7	4.7	5.4
MANGANESE	0.51	0.63	0.72	0.72
SAR	5.8	8.8	5.5	5.3
TDS	3560.	3230.	3020.	3220.
ION BALANCE	4.40%	2.90%	1.97%	2.43%
SAMPLED	pumped	pumped	pumped	bailed
REMARKS	-	-	rust	H2S odor

Water Chemistry

SWC-12295	130-59-2DDC1	28.1-29.1 ft.
WELL #	LOCATION	SCREENED INTERVAL

PARAMETER	DATE 1	DATE 2	DATE 3	DATE 4
	9-4-83	10-29-83	2-23-84	4-19-84
FIELD pH	6.7	7.0	5.8	7.2
LAB pH	7.9	8.1	7.9	7.9
FIELD TEMP	8.1	7.9	7.1	8.1
FIELD COND	4100.	3600.	2400.	1690.
LAB COND	6630.	6650.	6740.	6710.
SILICA	28.	27.	29.	23.
CALCIUM	280.	360.	290.	280.
MAGNESIUM	410.	410.	410.	410.
POTASSIUM	110.	110.	120.	95.
SODIUM	940.	980.	990.	980.
FLUORIDE	0.2	0.2	0.2	0.2
BICARBONATE	1410.	1460.	1500.	1480.
CARBONATE	0.	0.	0.	0.
SULFATE	3300.	3300.	3300.	3300.
CHLORIDE	65.	66.	67.	64.
NITRATE	1.	6.2	1.	5.6
BORON	0.61	0.22	0.55	0.60
IRON	6.2	5.9	3.9	11.
MANGANESE	0.53	0.49	0.54	0.50
SAR	8.3	8.4	8.8	8.7
TDS	5840.	5990.	5950.	5900.
ION BALANCE	1.23%	1.31%	0.46%	1.12%
SAMPLED	pumped	pumped	pumped	bailed
REMARKS	hvy. rust	rust H2S odor	rust	rust H2S odor

Water Chemistry

SWC-12296	130-59-2DDC2	5.6-13.6 ft.
WELL #	LOCATION	SCREENED INTERVAL

PARAMETER	DATE 1	DATE 2	DATE 3	DATE 4
	-	11-5-83	2-23-84	4-19-84
FIELD pH	-	7.2	6.6	7.2
LAB pH	-	8.0	8.0	7.7
FIELD TEMP	-	10.5	5.2	6.0
FIELD COND	-	940.	1380.	720.
LAB COND	-	982.	1020.	1320.
SILICA	-	31.	27.	17.
CALCIUM	-	27.	30.	44.
MAGNESIUM	-	39.	43.	66.
POTASSIUM	-	36.	36.	42.
SODIUM	-	130.	130.	160.
FLUORIDE	-	0.3	0.2	0.2
BICARBONATE	-	415.	421.	494.
CARBONATE	-	0.	0.	0.
SULFATE	-	180.	220.	310.
CHLORIDE	-	7.1	6.7	12.
NITRATE	-	1.4	0.4	0.6
BORON	-	0.30	0.27	0.30
IRON	-	0.51	0.10	1.1
MANGANESE	-	0.29	0.29	0.39
SAR	-	3.7	3.6	3.6
TDS	-	659.	701.	897.
ION BALANCE	-	2.04%	0.30%	2.45%
SAMPLED	-	bailed	bailed	bailed
REMARKS	-	-	-	H2S odor

Water Chemistry

USBR-140	130-59-3CBB	-
WELL #	LOCATION	SCREENED INTERVAL

PARAMETER	DATE 1	DATE 2	DATE 3	DATE 4
	6-1-83	10-28-83	2-26-84	4-26-84
FIELD pH	7.2	7.0	6.0	6.2
LAB pH	8.0	8.3	7.7	7.4
FIELD TEMP	7.6	9.5	6.6	7.3
FIELD COND	730.	790.	670.	560.
LAB COND	776.	784.	750.	769.
SILICA	25.	28.	28.	26.
CALCIUM	70.	78.	72.	73.
MAGNESIUM	32.	32.	31.	31.
POTASSIUM	9.6	11.	11.	11.
SODIUM	49.	50.	54.	49.
FLUORIDE	0.2	0.1	0.2	0.2
BICARBONATE	375.	391.	386.	390.
CARBONATE	0.	0.	0.	0.
SULFATE	110.	110.	93.	100.
CHLORIDE	46.	5.2	4.4	3.3
NITRATE	1.	1.7	1.	1.
BORON	0.07	0.06	0.06	0.05
IRON	1.6	3.7	1.3	2.9
MANGANESE	0.82	1.1	0.62	0.95
SAR	1.2	1.2	1.3	1.2
TDS	530.	514	487.	490.
ION BALANCE	6.95%	0.50%	2.04%	0.06%
SAMPLED	bailed	pumped	pumped	bailed
REMARKS	-	rust	-	-

Water Chemistry

USBR-135	130-59-4BAA	-
WELL #	LOCATION	SCREENED INTERVAL

PARAMETER	DATE 1	DATE 2	DATE 3	DATE 4
	6-1-83	10-28-83	2-18-84	4-24-84
FIELD pH	7.2	7.0	6.6	6.9
LAB pH	8.1	8.1	7.7	8.0
FIELD TEMP	6.3	9.3	5.4	5.7
FIELD COND	3600.	3300.	-	1260.
LAB COND	4560.	5160.	5080.	6750.
SILICA	25.	29.	27.	20.
CALCIUM	220.	310.	240.	240.
MAGNESIUM	250.	300.	260.	370.
POTASSIUM	15.	18.	18.	5.0
SODIUM	630.	730.	700.	1100.
FLUORIDE	0.3	0.3	0.2	0.3
BICARBONATE	589.	621.	631.	717.
CARBONATE	0.	0.	0.	0.
SULFATE	2300.	2700.	2700.	3900.
CHLORIDE	67.	49.	59.	54.
NITRATE	1.	3.8	1.	1.9
BORON	0.23	0.18	0.16	0.38
IRON	0.03	0.04	0.08	0.06
MANGANESE	0.07	0.04	0.05	0.00
SAR	6.9	7.1	7.4	10.
TDS	3800.	4450.	4320.	6040.
ION BALANCE	0.11%	3.22%	2.99%	2.22%
SAMPLED	bailed	pumped	pumped	bailed
REMARKS	-	-	-	pH rose fast

Water Chemistry

USBR-136	130-59-4BBB	-
WELL #	LOCATION	SCREENED INTERVAL

PARAMETER	DATE 1	DATE 2	DATE 3	DATE 4
	6-1-83	10-28-83	2-18-84	4-24-84
FIELD pH	6.9	7.2	6.6	6.8
LAB pH	8.1	8.1	7.7	7.4
FIELD TEMP	7.5	7.6	6.3	7.3
FIELD COND	1760.	1670.	-	650.
LAB COND	2140.	2160.	2170.	3190.
SILICA	12.	27.	30.	27.
CALCIUM	150.	160.	150.	190.
MAGNESIUM	84.	83.	82.	91.
POTASSIUM	12.	13.	13.	13.
SODIUM	230.	230.	240.	250.
FLUORIDE	0.2	0.2	0.2	0.2
BICARBONATE	575.	578.	592.	587.
CARBONATE	0.	0.	0.	0.
SULFATE	730.	719.	720.	750.
CHLORIDE	50.	45.	50.	44.
NITRATE	0.1	5.6	1.	0.0
BORON	0.15	0.13	0.18	0.17
IRON	1.9	3.8	2.5	2.9
MANGANESE	0.47	0.56	0.41	0.54
SAR	3.7	3.7	3.9	3.7
TDS	1550.	1570.	1580.	1660.
ION BALANCE	2.6%	1.33%	2.19%	3.09%
SAMPLED	bailed	pumped	pumped	bailed
REMARKS	-	rust	-	-

Water Chemistry

USBR-28 WELL #		130-59-4DDD LOCATION		- SCREENED INTERVAL
PARAMETER	DATE 1	DATE 2	DATE 3	DATE 4
	6-1-83	11-4-83	-	4-26-84
FIELD pH	6.9	6.7	-	6.4
LAB pH	8.1	8.1	-	7.4
FIELD TEMP	7.5	8.9	-	7.2
FIELD COND	770.	650.	-	540.
LAB COND	808.	795.	-	779.
SILICA	11.	30.	-	28.
CALCIUM	80.	91.	-	79.
MAGNESIUM	37.	34.	-	40.
POTASSIUM	6.4	7.5	-	7.1
SODIUM	40.	38.	-	34.
FLUORIDE	0.2	0.3	-	0.2
BICARBONATE	452.	463.	-	446.
CARBONATE	0.	0.	-	0.
SULFATE	63.	56.	-	52.0
CHLORIDE	11.	6.7	-	8.8
NITRATE	1.	1.	-	1.
BORON	0.06	0.09	-	0.06
IRON	0.	0.57	-	1.6
MANGANESE	0.66	1.2	-	0.76
SAR	0.9	0.9	-	0.8
TDS	473.	494.	-	473.
ION BALANCE	0.72%	1.05%	-	1.25%
SAMPLED	bailed	pumped	-	bailed
REMARKS	-	org. odor	-	-

Water Chemistry

USBR-138 WELL # | 130-59-5ADD LOCATION | - SCREENED INTERVAL

PARAMETER	DATE 1 6-1-83	DATE 2 11-4-83	DATE 3 2-18-84	DATE 4 4-24-84
FIELD pH	6.8	6.8	6.3	5.9
LAB pH	8.2	7.9	7.6	7.6
FIELD TEMP	7.0	8.7	6.1	6.9
FIELD COND	970.	780.	-	420.
LAB COND	959.	965.	958.	984.
SILICA	25.	29.	29.	22.
CALCIUM	98.	110.	100.	110.
MAGNESIUM	38.	37.	38.	38.
POTASSIUM	8.0	9.4	9.2	7.5
SODIUM	47.	54.	57.	56.
FLUORIDE	0.1	0.1	0.1	0.1
BICARBONATE	545.	501.	515.	519.
CARBONATE	0.	0.	0.	0.
SULFATE	72.	92.	82.	96.
CHLORIDE	31.	31.	24.	22.
NITRATE	1.	2.3	1.	0.7
BORON	0.10	0.08	0.06	0.09
IRON	1.7	5.5	3.5	3.0
MANGANESE	0.87	1.2	1.0	0.90
SAR	1.0	1.1	1.2	1.2
TDS	591.	619.	599.	612.
ION BALANCE	4.96%	0.32%	0.09%	0.44%
SAMPLED	bailed	pumped	pumped	bailed
REMARKS	-	rust	-	-

Water Chemistry

USBR-146 WELL # | 130-59-8AAA LOCATION | - SCREENED INTERVAL

PARAMETER	DATE 1 6-1-83	DATE 2 11-4-83	DATE 3 2-18-84	DATE 4 4-24-84
FIELD pH	6.7	6.7	6.3	6.7
LAB pH	8.3	8.1	7.8	7.6
FIELD TEMP	6.8	8.9	4.8	7.1
FIELD COND	610.	575.	-	420.
LAB COND	589.	650.	636.	723.
SILICA	12.	31.	30.	19.
CALCIUM	67.	78.	74.	82.
MAGNESIUM	25.	26.	25.	29.
POTASSIUM	4.5	4.2	4.5	4.7
SODIUM	23.	27.	28.	30.
FLUORIDE	0.1	0.2	0.2	0.2
BICARBONATE	321.	347.	334.	363.
CARBONATE	0.	0.	0.	0.
SULFATE	58.	71.	62.	92.
CHLORIDE	3.9	5.4	5.8	7.9
NITRATE	0.	1.6	1.	1.7
BORON	0.04	0.06	0.04	0.03
IRON	0.11	4.4	0.89	2.3
MANGANESE	0.28	0.46	0.32	0.35
SAR	0.6	0.7	0.7	0.7
TDS	352.	420.	397.	448.
ION BALANCE	0.53%	0.34%	1.%	1.37%
SAMPLED	bailed	pumped	pumped	bailed
REMARKS	-	-	-	color: lt. brn.

Water Chemistry

USBR-29 WELL # | 130-59-10AAA LOCATION | - SCREENED INTERVAL

PARAMETER	DATE 1	DATE 2	DATE 3	DATE 4
	6-1-83	-	-	-
FIELD pH	7.5	-	-	-
LAB pH	8.6	-	-	-
FIELD TEMP	7.8	-	-	-
FIELD COND	900.	-	-	-
LAB COND	834.	-	-	-
SILICA	20.	-	-	-
CALCIUM	50.	-	-	-
MAGNESIUM	27.	-	-	-
POTASSIUM	6.6	-	-	-
SODIUM	93.	-	-	-
FLUORIDE	0.3	-	-	-
BICARBONATE	424.	-	-	-
CARBONATE	17.	-	-	-
SULFATE	37.	-	-	-
CHLORIDE	40.	-	-	-
NITRATE	1.	-	-	-
BORON	0.31	-	-	-
IRON	0.17	-	-	-
MANGANESE	0.63	-	-	-
SAR	2.6	-	-	-
TDS	502.	-	-	-
ION BALANCE	2.83%	-	-	-
SAMPLED	bailed	-	-	-
REMARKS	-	-	-	-

Water Chemistry

USBR-144 | 130-59-10ABB | -
WELL # | LOCATION | SCREENED INTERVAL

PARAMETER	DATE 1	DATE 2	DATE 3	DATE 4
	6-1-83	11-4-83	-	4-26-84
FIELD pH	7.2	6.7	-	6.3
LAB pH	7.9	7.9	-	7.9
FIELD TEMP	6.8	7.9	-	7.2
FIELD COND	760.	610.	-	530.
LAB COND	784.	762.	-	751.
SILICA	29.	31.	-	26.
CALCIUM	100.	110.	-	99.
MAGNESIUM	32.	32.	-	28.
POTASSIUM	6.2	6.5	-	6.3
SODIUM	14.	16.	-	18.
FLUORIDE	0.4	0.5	-	0.4
BICARBONATE	438.	424.	-	427.
CARBONATE	0.	0.	-	0.
SULFATE	63.	64.	-	65.
CHLORIDE	18.	6.9	-	5.1
NITRATE	1.	1.8	-	0.2
BORON	0.08	0.05	-	0.05
IRON	1.4	2.0	-	1.8
MANGANESE	1.6	1.7	-	1.4
SAR	0.3	0.3	-	0.4
TDS	483.	481.	-	461.
ION BALANCE	3.73%	2.63%	-	1.98%
SAMPLED	bailed	bailed	-	bailed
REMARKS	-	-	-	-

Water Chemistry

SWC-12274	130-59-11BBB2	35.1-36.1 ft.
WELL #	LOCATION	SCREENED INTERVAL

PARAMETER	DATE 1	DATE 2	DATE 3	DATE 4
	9-3-83	10-29-83	2-25-84	4-25-84
FIELD pH	7.1	7.7	6.5	6.3
LAB pH	7.8	8.1	7.9	8.0
FIELD TEMP	9.8	8.3	6.7	7.9
FIELD COND	2100.	2300.	1830.	1160.
LAB COND	2370.	3040.	3003.	3070.
SILICA	46.	42.	40.	37.
CALCIUM	130.	160.	190.	230.
MAGNESIUM	88.	100.	110.	110.
POTASSIUM	31.	6.5	83.	75.
SODIUM	300.	380.	380.	390.
FLUORIDE	0.2	0.1	0.1	0.2
BICARBONATE	488.	658.	705.	610.
CARBONATE	0.	0.	0.	0.
SULFATE	720.	960.	1000.	1000.
CHLORIDE	140.	180.	180.	180.
NITRATE	1.	0.4	1.	1.
BORON	0.22	0.17	0.07	0.19
IRON	0.03	2.0	1.6	1.9
MANGANESE	0.19	0.30	0.40	0.43
SAR	5.0	5.8	5.4	5.3
TDS	1700.	2160.	2330.	2330.
ION BALANCE	1.10%	4.30%	0.40%	4.63%
SAMPLED	pumped	pumped	pumped	bailed
REMARKS	rust	rust	rust	-

Water Chemistry

SWC-12275	130-59-11BBB3	9.0-17.0 ft.
WELL #	LOCATION	SCREENED INTERVAL

PARAMETER	DATE 1	DATE 2	DATE 3	DATE 4
	9-3-83	11-5-83	2-25-84	4-25-84
FIELD pH	6.7	7.1	6.6	6.7
LAB pH	8.2	7.9	8.0	7.8
FIELD TEMP	9.4	10.1	5.0	6.8
FIELD COND	780.	690.	910.	660.
LAB COND	884.	864.	880.	871.
SILICA	30.	30.	25.	26.
CALCIUM	48.	51.	57.	51.
MAGNESIUM	22.	22.	25.	23.
POTASSIUM	9.8	9.4	7.9	8.9
SODIUM	120.	110.	110.	110.
FLUORIDE	0.3	0.4	0.5	0.4
BICARBONATE	448.	432.	453.	448.
CARBONATE	0.	0.	0.	0.
SULFATE	84.	71.	77.	73.
CHLORIDE	25.	23.	24.	20.
NITRATE	1.	1.	0.5	0.1
BORON	0.24	0.26	0.21	0.27
IRON	0.18	0.43	0.02	0.30
MANGANESE	0.29	0.31	0.20	0.25
SAR	3.6	3.2	3.0	3.2
TDS	562.	532.	550.	534.
ION BALANCE	0.82%	0.69%	0.76%	0.05%
SAMPLED	air lift	bailed	pumped	bailed
REMARKS	-	-	-	-

Water Chemistry

SWC-12289	130-59-11BBB4	57.0-58.0 ft.
WELL #	LOCATION	SCREENED INTERVAL

PARAMETER	DATE 1	DATE 2	DATE 3	DATE 4
	9-4-83	10-29-83	2-25-84	4-25-84
FIELD pH	8.0	7.5	6.4	6.6
LAB pH	7.8	8.0	7.9	8.1
FIELD TEMP	10.0	9.0	6.5	7.7
FIELD COND	1710.	1625.	1410.	940.
LAB COND	1980.	2210.	2280.	2190.
SILICA	22.	27.	26.	23.
CALCIUM	95.	140.	150.	130.
MAGNESIUM	38.	45.	45.	42.
POTASSIUM	46.	20.	18.	16.
SODIUM	290.	320.	320.	340.
FLUORIDE	0.4	0.3	0.3	0.4
BICARBONATE	477.	520.	591.	546.
CARBONATE	0.	0.	0.	0.
SULFATE	510.	590.	560.	590.
CHLORIDE	95.	140.	140.	130.
NITRATE	1.0	7.7	1.	6.3
BORON	0.58	0.57	0.73	0.70
IRON	0.03	1.2	0.77	1.5
MANGANESE	0.47	0.50	0.46	0.47
SAR	6.4	6.0	5.9	6.6
TDS	1330.	1550.	1550.	1550.
ION BALANCE	1.20%	0.46%	0.45%	0.24%
SAMPLED	pumped	pumped	pumped	bailed
REMARKS	-	-	-	H2S odor

Water Chemistry

USBR-212A	130-59-12DCC	17.0-18.2 ft.
WELL #	LOCATION	SCREENED INTERVAL

PARAMETER	DATE 1	DATE 2	DATE 3	DATE 4
	5-31-83	11-5-83	2-24-84	5-15-84
FIELD pH	7.1	6.8	7.1	6.8
LAB pH	7.8	8.0	7.9	7.5
FIELD TEMP	6.2	8.5	6.5	7.0
FIELD COND	1380.	820.	910.	-
LAB COND	1500.	1230.	1240.	1230.
SILICA	25.	28.	28.	27.
CALCIUM	140.	130.	120.	120.
MAGNESIUM	61.	48.	47.	45.
POTASSIUM	14.	13.	12.	12.
SODIUM	120.	100.	100.	110.
FLUORIDE	0.2	0.2	0.2	0.2
BICARBONATE	736.	759.	775.	761.
CARBONATE	0.	0.	0.	0.
SULFATE	280.	95.	94.	96.
CHLORIDE	6.5	3.2	3.2	3.3
NITRATE	3.2	4.1	1.	2.5
BORON	0.10	0.10	0.09	0.11
IRON	7.8	5.4	3.8	7.2
MANGANESE	0.84	0.82	0.72	0.66
SAR	2.1	1.9	2.0	2.2
TDS	1020.	802.	792.	799.
ION BALANCE	1.51%	1.78%	0.89%	0.61%
SAMPLED	bailed	bailed	pumped	bailed
REMARKS	hvy. rust	-	rust	-

Water Chemistry

USBR-212B	130-59-12DCC	4.7-5.9 ft.
WELL #	LOCATION	SCREENED INTERVAL

PARAMETER	DATE 1	DATE 2	DATE 3	DATE 4
	5-31-83	11-5-83	-	5-15-84
FIELD pH	7.3	7.0	-	6.8
LAB pH	7.6	7.9	-	7.6
FIELD TEMP	6.2	9.9	-	6.0
FIELD COND	600.	470.	-	-
LAB COND	547.	556.	-	539.
SILICA	21.	25.	-	23.
CALCIUM	45.	43.	-	45.
MAGNESIUM	16.	16.	-	15.
POTASSIUM	6.8	7.7	-	6.6
SODIUM	52.	51.	-	53.
FLUORIDE	0.3	0.3	-	0.3
BICARBONATE	305.	284.	-	297.
CARBONATE	0.	0.	-	0.
SULFATE	49.	38.	-	41.
CHLORIDE	91.	3.1	-	0.0
NITRATE	1.	2.4	-	1.
BORON	0.13	0.12	-	0.07
IRON	0.22	0.05	-	0.14
MANGANESE	0.16	2.3	-	3.0
SAR	1.7	1.7	-	1.8
TDS	433.	329.	-	334.
ION BALANCE	17.98%	2.6%	-	1.71%
SAMPLED	bailed	bailed	-	bailed
REMARKS	-	mud	-	-

Water Chemistry

USBR-214	130-59-13BBB	18.4-19.6 ft.
WELL #	LOCATION	SCREENED INTERVAL

PARAMETER	DATE 1 5-31-83	DATE 2 11-5-83	DATE 3 2-24-84	DATE 4 4-25-84
FIELD pH	7.0	6.8	7.1	6.6
LAB pH	7.9	7.8	7.5	7.8
FIELD TEMP	7.3	9.0	7.1	6.8
FIELD COND	960.	710.	890.	620.
LAB COND	1030.	941.	930.	993.
SILICA	25.	30.	29.	25.
CALCIUM	120.	110.	120.	120.
MAGNESIUM	47.	44.	43.	42.
POTASSIUM	7.3	6.7	6.9	6.3
SODIUM	46.	35.	38.	36.
FLUORIDE	0.2	0.3	0.3	0.2
BICARBONATE	572.	594.	595.	612.
CARBONATE	0.	0.	0.	0.
SULFATE	120.	49.	47.	68.
CHLORIDE	11.	0.5	2.5	2.0
NITRATE	1.	1.	1.	1.1
BORON	0.07	0.05	0.07	0.07
IRON	3.6	3.5	2.2	3.6
MANGANESE	1.3	1.1	1.1	1.1
SAR	0.9	0.7	0.8	0.7
TDS	664.	574.	584.	606.
ION BALANCE	0.7%	0.04%	2.34%	1.63%
SAMPLED	bailed	air lift	pumped	bailed
REMARKS	-	-	rust	-

Water Chemistry

USBR-213 WELL # | 130-59-13BCC LOCATION | 17.4-18.9 ft. SCREENED INTERVAL

PARAMETER	DATE 1 5-31-83	DATE 2 11-5-83	DATE 3 2-24-84	DATE 4 4-25-84
FIELD pH	7.1	6.8	7.2	6.6
LAB pH	8.0	8.0	7.8	7.7
FIELD TEMP	6.8	9.2	6.6	5.2
FIELD COND	880.	640.	810.	540.
LAB COND	908.	775.	798.	671.
SILICA	24.	29.	27.	22.
CALCIUM	89.	91.	93.	80.
MAGNESIUM	40.	31.	29.	24.
POTASSIUM	13.	11.	9.2	7.1
SODIUM	52.	39.	40.	23.
FLUORIDE	0.2	0.2	0.2	0.2
BICARBONATE	476.	493.	512.	414.
CARBONATE	0.	0.	0.	0.
SULFATE	140.	30.	35.	33.
CHLORIDE	9.8	2.6	2.8	2.0
NITRATE	1.	0.9	0.2	0.1
BORON	0.08	0.04	0.02	0.04
IRON	0.03	0.12	0.04	0.07
MANGANESE	1.0	2.13	2.1	1.8
SAR	1.1	0.9	0.9	0.6
TDS	604.	480.	491.	397.
ION BALANCE	3.3%	1.57%	1.10%	2.79%
SAMPLED	bailed	bailed	pumped	bailed
REMARKS	-	-	-	-

Water Chemistry

USBR-131 — 131-59-33CBB — -
WELL # — LOCATION — SCREENED INTERVAL

PARAMETER	DATE 1 6-1-83	DATE 2 10-28-83	DATE 3 2-18-84	DATE 4 4-26-84
FIELD pH	7.1	7.5	6.5	6.5
LAB pH	8.2	8.2	7.9	7.6
FIELD TEMP	7.9	10.	7.2	7.6
FIELD COND	570.	540.	-	470.
LAB COND	540.	586.	590.	561.
SILICA	30.	30.	32.	28.
CALCIUM	62.	72.	71.	67.
MAGNESIUM	28.	28.	30.	29.
POTASSIUM	2.7	2.2	1.6	1.4
SODIUM	4.0	5.0	4.9	4.7
FLUORIDE	0.2	0.2	0.2	0.2
BICARBONATE	283.	265.	293.	296.
CARBONATE	0.	0.	0.	0.
SULFATE	15.	20.	19.	19.
CHLORIDE	14.	4.5	4.0	1.2
NITRATE	50.	8.	56.	40.
BORON	0.06	0.08	0.07	0.04
IRON	0.01	0.02	0.01	0.01
MANGANESE	0.03	0.08	0.06	0.05
SAR	0.1	0.1	0.1	0.1
TDS	345.	381.	362.	337.
ION BALANCE	4.50%	1.20%	0.24%	0.25%
SAMPLED	bailed	pumped	pumped	bailed
REMARKS	-	-	-	-

Water Chemistry

USBR-18A | 131-59-33DAA | -
WELL # | LOCATION | SCREENED INTERVAL

PARAMETER	DATE 1 6-1-83	DATE 2 10-28-83	DATE 3 2-18-84	DATE 4 4-24-84
FIELD pH	7.2	7.1	6.7	7.0
LAB pH	8.1	8.1	7.9	7.8
FIELD TEMP	8.1	9.1	6.5	8.0
FIELD COND	725.	610.	-	470.
LAB COND	680.	649.	699.	701.
SILICA	29.	29.	31.	21.
CALCIUM	83.	91.	86.	89.
MAGNESIUM	27.	26.	27.	27.
POTASSIUM	5.4	5.7	5.8	3.0
SODIUM	21.	23.	24.	24.
FLUORIDE	0.4	0.3	0.3	0.3
BICARBONATE	371.	348.	376.	371.
CARBONATE	0.	0.	0.	0.
SULFATE	68.	73.	73.	77.
CHLORIDE	14.	6.4	6.0	4.7
NITRATE	1.	2.0	1.	0.3
BORON	0.10	0.07	0.08	0.09
IRON	0.07	0.62	0.29	0.79
MANGANESE	0.67	1.1	1.1	1.0
SAR	0.5	0.5	0.6	0.6
TDS	433.	429.	440.	431.
ION BALANCE	3.39%	2.49%	1.22%	0.32%
SAMPLED	bailed	pumped	pumped	bailed
REMARKS	-	-	-	-

Water Chemistry

USBR-22 WELL # | 131-59-33DDD LOCATION | - SCREENED INTERVAL

PARAMETER	DATE 1 6-1-83	DATE 2 10-28-83	DATE 3 2-18-84	DATE 4 4-24-84
FIELD pH	9.2	7.4	6.9	7.4
LAB pH	7.7	8.2	8.5	7.5
FIELD TEMP	6.9	10.8	4.7	6.1
FIELD COND	1670.	2300.	-	820.
LAB COND	2060.	2760.	3560.	1690.
SILICA	2.2	2.5	1.8	6.2
CALCIUM	17.	39.	29.	48.
MAGNESIUM	68.	110.	130.	60.
POTASSIUM	15.	22.	22.	13.
SODIUM	340.	410.	570.	230.
FLUORIDE	0.2	0.2	0.1	0.2
BICARBONATE	278.	483.	407.	349.
CARBONATE	0.	0.	17.	0.
SULFATE	760.	1100.	1600.	570.
CHLORIDE	18.	25.	30.	12.
NITRATE	26.	0.7	0.8	1.1
BORON	0.04	0.09	0.08	0.12
IRON	0.02	0.06	0.06	0.07
MANGANESE	0.02	0.07	0.07	0.00
SAR	8.3	7.6	10.	5.2
TDS	1380.	1950.	2600.	1110.
ION BALANCE	0.60%	3.53%	4.97%	0.78%
SAMPLED	bailed	bailed	bailed	bailed
REMARKS	rust	color: lt. brn. org. odor	color: black org. odor	pH rose fast

Water Chemistry

USBR-134	131-59-34DCC	-
WELL #	LOCATION	SCREENED INTERVAL

PARAMETER	DATE 1 6-1-83	DATE 2 10-28-83	DATE 3 2-18-84	DATE 4 4-24-84
FIELD pH	7.2	7.3	6.5	7.4
LAB pH	8.0	8.3	8.0	7.9
FIELD TEMP	7.6	9.6	6.1	6.8
FIELD COND	670.	680.	-	460.
LAB COND	613.	661.	614.	638.
SILICA	26.	28.	29.	24.
CALCIUM	68.	72.	70.	76.
MAGNESIUM	24.	27.	25.	25.
POTASSIUM	6.1	6.6	6.9	6.8
SODIUM	24.	28.	31.	26.
FLUORIDE	0.2	0.2	0.3	0.3
BICARBONATE	354.	365.	359.	373.
CARBONATE	0.	0.	0.	0.
SULFATE	34.	51.	44.	45.
CHLORIDE	15.	8.5	6.4	3.5
NITRATE	1.	1.8	1.	0.9
BORON	0.07	0.05	0.08	0.07
IRON	0.12	0.	0.44	0.08
MANGANESE	0.27	0.30	0.32	0.11
SAR	0.6	0.7	0.8	0.7
TDS	373.	403.	391.	392.
ION BALANCE	2.96%	0.82%	0.43%	0.21%
SAMPLED	bailed	pumped	pumped	bailed
REMARKS	-	-	-	-

Water Chemistry

USBR-122 WELL # | 131-59-35DCC LOCATION | - SCREENED INTERVAL

PARAMETER	DATE 1 6-1-83	DATE 2 10-30-83	DATE 3 2-18-84	DATE 4 4-24-84
FIELD pH	7.2	7.3	6.3	6.9
LAB pH	8.0	8.2	8.0	7.7
FIELD TEMP	8.2	7.9	6.6	8.0
FIELD COND	630.	570.	-	440.
LAB COND	582.	581.	693.	671.
SILICA	12.	28.	29.	22.
CALCIUM	65.	83.	81.	76.
MAGNESIUM	22.	27.	27.	25.
POTASSIUM	5.5	6.0	6.0	4.0
SODIUM	22.	28.	27.	26.
FLUORIDE	0.2	0.3	0.2	0.3
BICARBONATE	375.	341.	409.	403.
CARBONATE	0.	0.	0.	0.
SULFATE	19.	51.	48.	43.
CHLORIDE	5.1	0.3	4.2	0.7
NITRATE	1.	0.5	1.	0.5
BORON	0.07	0.06	0.08	0.09
IRON	0.08	0.13	0.10	0.06
MANGANESE	0.70	0.71	0.72	0.60
SAR	0.6	0.7	0.7	0.7
TDS	338.	393.	425.	397.
ION BALANCE	4.4%	7.21%	1.75%	6.35%
SAMPLED	bailed	pumped	pumped	bailed
REMARKS	-	-	-	-

APPENDIX E

TEXTURAL CHARACTERISTICS OF SEDIMENTS AS ANALYZED BY THE USBR LAB

WELL#	LOCATION	DEPTH (inches)	SAND:SILT:CLAY (percent)	TEXTURAL CLASS (Lab)
198	130-59-1CCC	0-6	55:27:18	Fine sandy loam
		6-36	38:25:37	Clay loam
		36-48	62:17:21	Sandy clay loam
		48-78	66:17:17	Sandy loam
		78-132	89:06:05	Sand
		132-276	87:08:05	Loamy coarse sand
		276-372	95:02:03	Fine sand
		372-396	04:86:10	Silt
199	130-59-1DDD	0-18	42:38:20	Loam
		18-90	04:70:26	Silty loam
		90-114	84:07:09	Loamy coarse sand
		114-306	86:08:06	Loamy sand
		306-396	85:10:05	Loamy coarse sand
200	130-58-7CBB	0-6	60:25:15	Fine sandy loam
		6-18	62:17:21	Sandy clay loam
		18-42	57:27:16	Fine sandy loam
		42-56	86:09:05	Loamy fine sand
		56-150	86:09:05	Loamy fine sand
		150-330	86:07:07	Loamy coarse sand
		330-372	85:09:06	Loamy coarse sand
		372-396	13:64:23	Silty loam
201	130-58-7CCC	0-12	35:31:34	Clay loam
		12-36	31:27:42	Clay
		36-48	67:17:16	Fine sand loam
		48-102	84:09:07	Loamy sand
		102-216	94:03:03	Coarse sand
202	130-58-17CCC	0-16	77:10:13	Fine sandy loam
		16-36	86:06:08	Loamy fine sand
		36-60	19:53:28	Silty clay
		60-96	20:22:58	Clay
		96-216	90:04:06	Sand
203	130-58-17BCC	0-12	73:15:12	Fine sandy loam
		12-24	88:03:09	Loamy fine sand
		24-60	11:66:23	Silty loam
		60-72	06:20:74	Clay
		72-168	93:02:05	Fine sand
		168-252	84:08:08	Loamy sand
		252-258	09:84:07	Silt
		258-396	96:02:02	Coarse sand
204	130-58-17BBB	0-12	42:35:23	Loam
		12-36	20:41:39	Silty clay loam
		36-84	04:82:14	Silty loam
		84-204	01:20:79	Clay
		204-276	85:06:09	Loamy sand

205	130-58-18DBB	0-16	73:13:14	Fine sandy loam
		16-78	86:06:08	Loamy sand
		78-108	19:59:22	Silty loam
		108-128	36:55:09	Silty loam
		128-156	82:11:07	Loamy sand
		156-396	89:05:06	Fine sand
206	130-58-18DCC	0-30	41:52:07	Sandy loam
		30-48	86:04:10	Loamy sand
		48-72	27:64:09	Silty loam
		72-150	92:03:05	Sand
		150-192	89:08:03	Coarse sand
		192-216	90:06:04	Fine sand
		216-396	91:06:03	Coarse sand
207	130-58-19BBB	0-18	65:13:22	Sandy clay loam
		18-54	88:07:05	Fine sand
		54-72	90:05:05	Fine sand
		72-384	94:03:03	Coarse sand
		384-396	74:14:12	Fine sandy loam
208	130-58-17CDD	0-12	60:18:22	Sandy clay loam
		12-66	85:08:07	Loamy sand
		66-168	88:06:06	Sand
		168-396	91:05:04	Sand
209	130-58-17BAA	0-36	56:32:12	Fine sandy loam
		36-54	68:20:12	Fine sandy loam
		54-88	22:65:13	Silty loam
		88-152	82:12:06	Loamy fine sand
		152-294	72:22:06	Very fine sandy loam
		294-396	93:05:02	Sand
210	130-58-19ADD	0-12	83:08:09	Loamy sand
		12-48	89:05:06	Sand
		48-60	27:48:25	Loam
		60-84	24:17:59	Clay
		84-336	89:06:05	Sand
		336-396	88:06:06	Fine sand
211	130-58-18BCC	0-24	72:13:15	Fine sandy loam
		24-48	87:06:07	Loamy fine sand
		48-90	93:04:03	Fine sand
		90-192	94:04:02	Sand
		192-300	94:03:03	Fine sand
		300-396	90:06:04	Coarse sand
212	130-59-12DCC	0-12	27:32:41	Clay
		12-48	28:31:41	Clay
		48-66	85:05:10	Loamy sand
		66-108	85:09:06	Loamy sand
		108-336	89:06:05	Coarse sand
		336-396	95:03:02	Fine sand

213	130-59-13BCC	0-12	70:15:15	Fine sandy loam
		12-30	85:07:08	Loamy sand
		30-54	89:05:06	Sand
		54-396	88:08:04	Sand
214	130-59-13BBB	0-24	58:19:23	Sandy clay loam
		24-66	92:02:06	Sand
		66-120	93:03:04	Sand
		120-152	91:03:06	Coarse sand
		152-288	87:09:04	Loamy sand

APPENDIX F

TEXTURAL CHARACTERISTICS OF SEDIMENTS OBTAINED BY THE NDSWC

LOCATION	DEPTH (feet)	SAND:SILT:CLAY (weight %)	GRAVEL (grams)	GYSPSUM (grams)	FIELD DESCRIP
130-59-1CCC	31-35	13:55:32	2.380	7.244	Silt
	36-40	25:49:26	2.062	7.047	Silt
	56-60	53:28:19	12.849	0.255	Till
130-59-1CCD	55-56	51:37:12	24.368	0.089	Till
130-59-1CDD	41-45	29:49:22	14.198	1.033	Silt
	46-50	47:34:19	7.666	0.377	Silt
	56-60	36:43:21	9.779	0.456	Till
130-59-1DDD	31-35	94:06:00	8.457	-	Sand
	36-40	93:06:01	10.444	-	Sand, gravel
	46-50	34:35:31	25.205	3.969	Silt
	56-60	18:56:26	17.562	2.089	Silt
130-59-2BBB	16-20	06:18:76	0.000	-	Clay
	36-40	67:17:16	23.265	-	Sand, gravel
	46-50	42:36:22	11.795	-	Till
	56-60	34:39:27	1.302	-	Till
130-59-2CBB	36-40	65:26:09	11.259	-	Till
	46-50	47:36:17	15.001	-	Till
	56-60	44:36:20	8.469	-	Till
130-59-2CCB	45-50	40:36:24	9.901	-	Till
	56-60	43:34:23	7.624	-	Till
130-59-2CDD	46-50	42:39:19	9.259	-	Till
	56-60	42:40:18	4.392	-	Till
130-59-11BBB	34-40	79:15:06	6.772	-	Till
	46-50	44:33:23	8.641	-	Till
	56-60	41:32:27	2.426	-	Till

APPENDIX G

MINERAL SATURATION DATA

Figure 66. Calcite saturation along the east-west traverse (September, 1983).

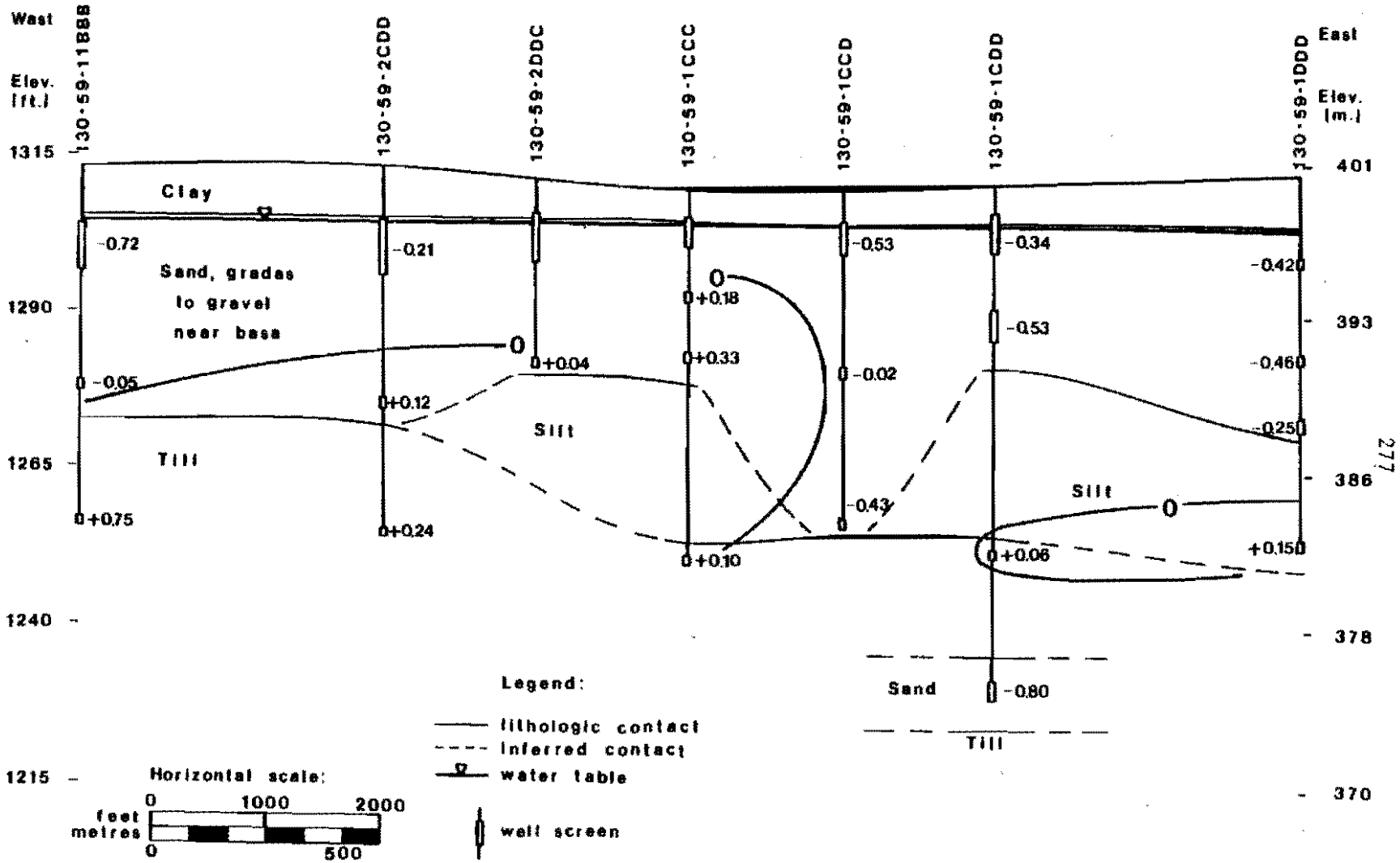

West
East
Elev. (ft.)
Elev. (m.)
1315
1290
1265
1240
1215
401
393
386
378
370
130-59-11BBB
130-59-2CDD
130-59-2DDC
130-59-1CCC
130-59-1CCD
130-59-1CDD
130-59-1DDD
Clay
Sand, gradas to gravel near base
Till
Silt
Sand
Till
-0.72
-0.21
-0.53
-0.34
-0.420
-0.53
-0.460
-0.250
-0.05
+0.04
+0.18
+0.33
+0.12
-0.02
-0.43
+0.75
+0.24
+0.10
+0.06
+0.150
-0.80
Legend:
lithologic contact
inferred contact
water table
well screen
Horizontal scale:
feet
metres
0
1000
2000
500
277

Figure 67. Calcite saturation along the east-west traverse (October-November, 1983).

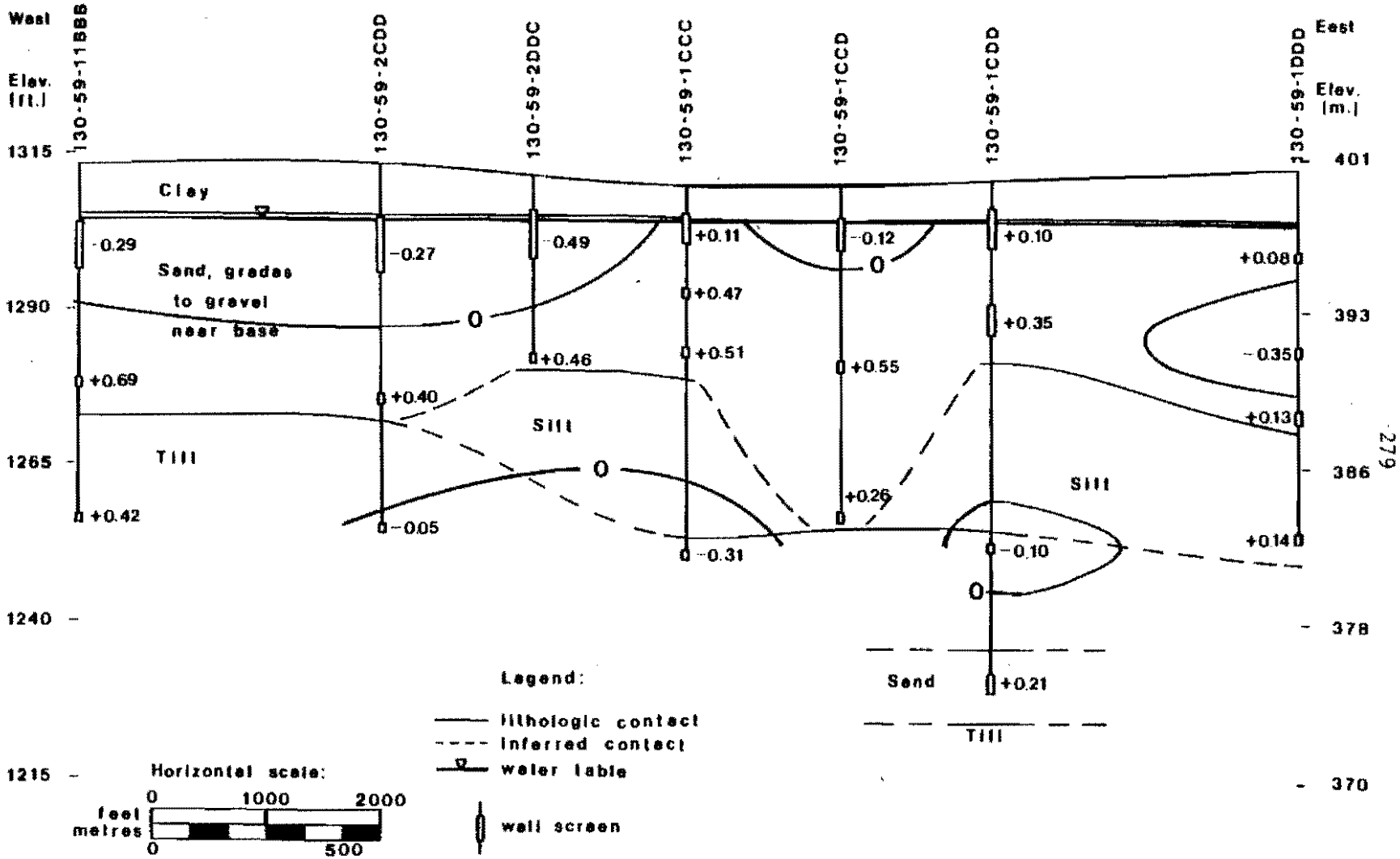

West
Elev. (ft.)
1315
1290
1265
1240
1215
130-59-11BBB
130-59-2CDD
130-59-2DDC
130-59-1CCC
130-59-1CCD
130-59-1CDD
130-59-1DDD
East
Elev. (m.)
401
393
386
378
370
Clay
Sand, grades to gravel near base
Till
Silt
Sand
Till
-0.29
-0.27
-0.49
+0.11
-0.12
+0.10
+0.080
+0.47
+0.35
+0.69
+0.40
+0.46
+0.51
+0.55
-0.350
+0.13
+0.42
-0.05
-0.31
+0.26
-0.10
+0.140
+0.21
0
Legend:
lithologic contact
inferred contact
water table
well screen
Horizontal scale:
feet
metres
0
1000
2000
500
279

Figure 68. Calcite saturation along the east-west traverse (February, 1984).

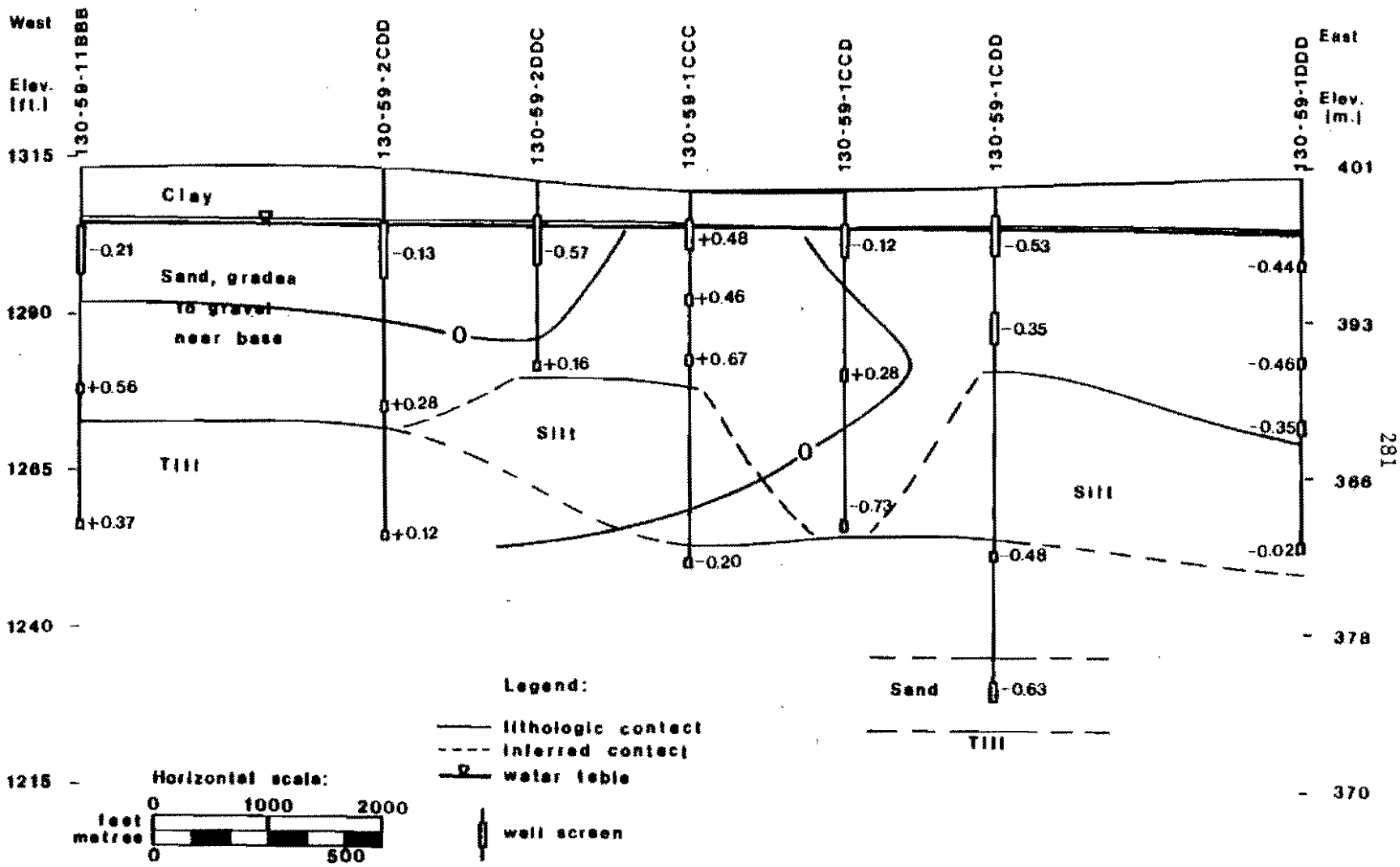

West
East
Elev. (ft.)
Elev. (m.)
1315
1290
1265
1240
1215
401
393
386
378
370
130-59-11BBB
130-59-2CDD
130-59-2DDC
130-59-1CCC
130-59-1CCD
130-59-1CDD
130-59-1DDD
Clay
Sand, grades to gravel near base
Silt
Till
Sand
Till
-0.21
-0.13
-0.57
+0.48
-0.12
-0.53
-0.440
+0.46
-0.35
+0.56
+0.16
+0.67
+0.28
-0.460
+0.28
-0.35
+0.37
+0.12
-0.73
-0.20
-0.48
-0.020
-0.63
Legend:
lithologic contact
inferred contact
water table
well screen
Horizontal scale:
feet
metres
0
1000
2000
500
281

Figure 69. Calcite saturation along the east-west traverse (April, 1984).

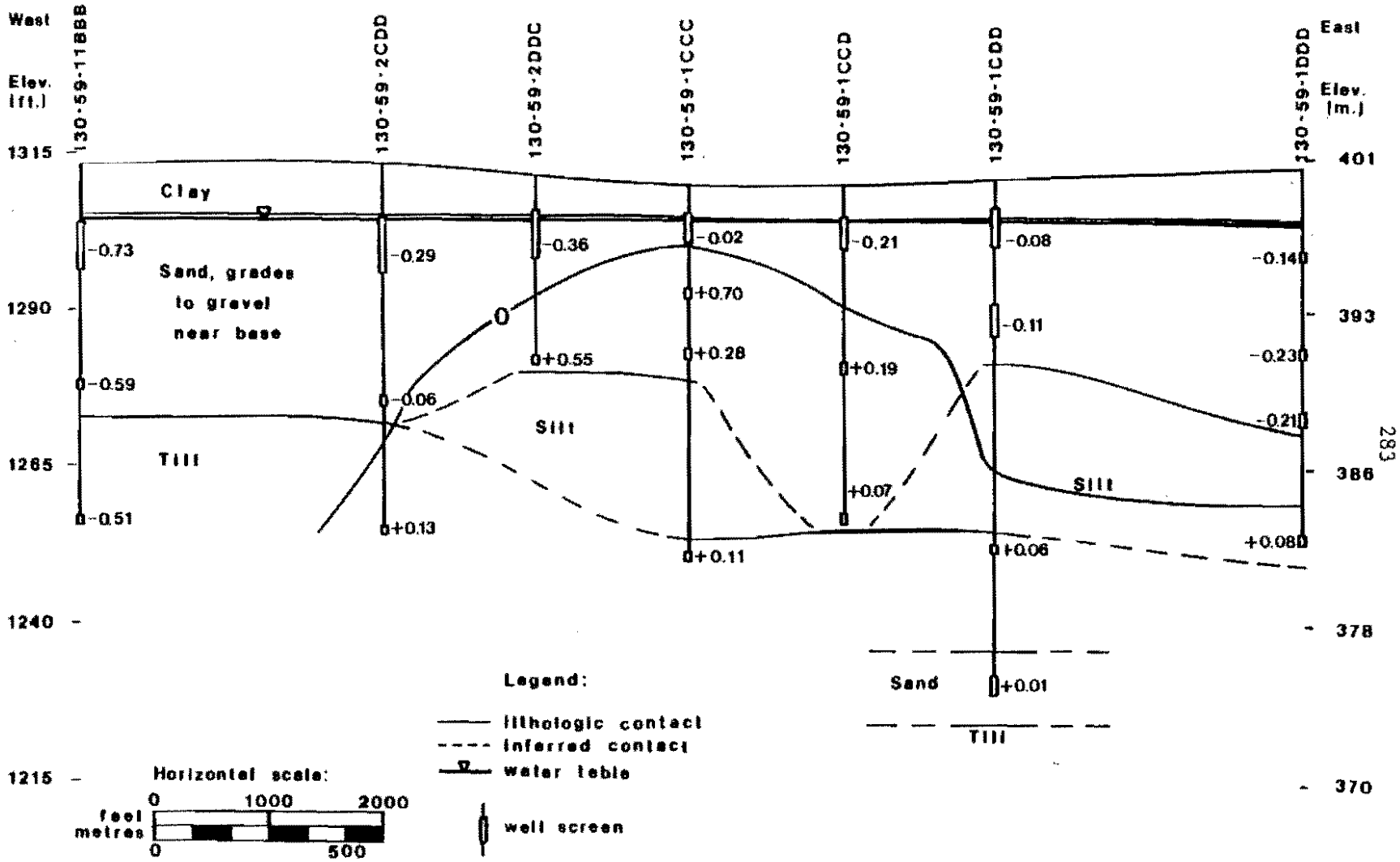

West
Elev. (ft.)
East
Elev. (m.)
130-59-11BBB
130-59-2CDD
130-59-2DDC
130-59-1CCC
130-59-1CCD
130-59-1CDD
130-59-1DDD
1315
1290
1265
1240
1215
401
393
386
378
370
Clay
Sand, grades to gravel near base
Till
Silt
Sand
-0.73
-0.59
-0.51
-0.29
-0.36
-0.02
-0.21
-0.08
-0.140
-0.230
-0.210
+0.70
+0.28
+0.19
+0.07
+0.11
+0.06
+0.080
+0.01
+0.13
+0.55
-0.06
-0.11
0
Legend:
lithologic contact
inferred contact
water table
well screen
Horizontal scale:
feet
metres
0
1000
2000
500
283

Figure 70. Dolomite saturation along the east-west traverse (September, 1983).

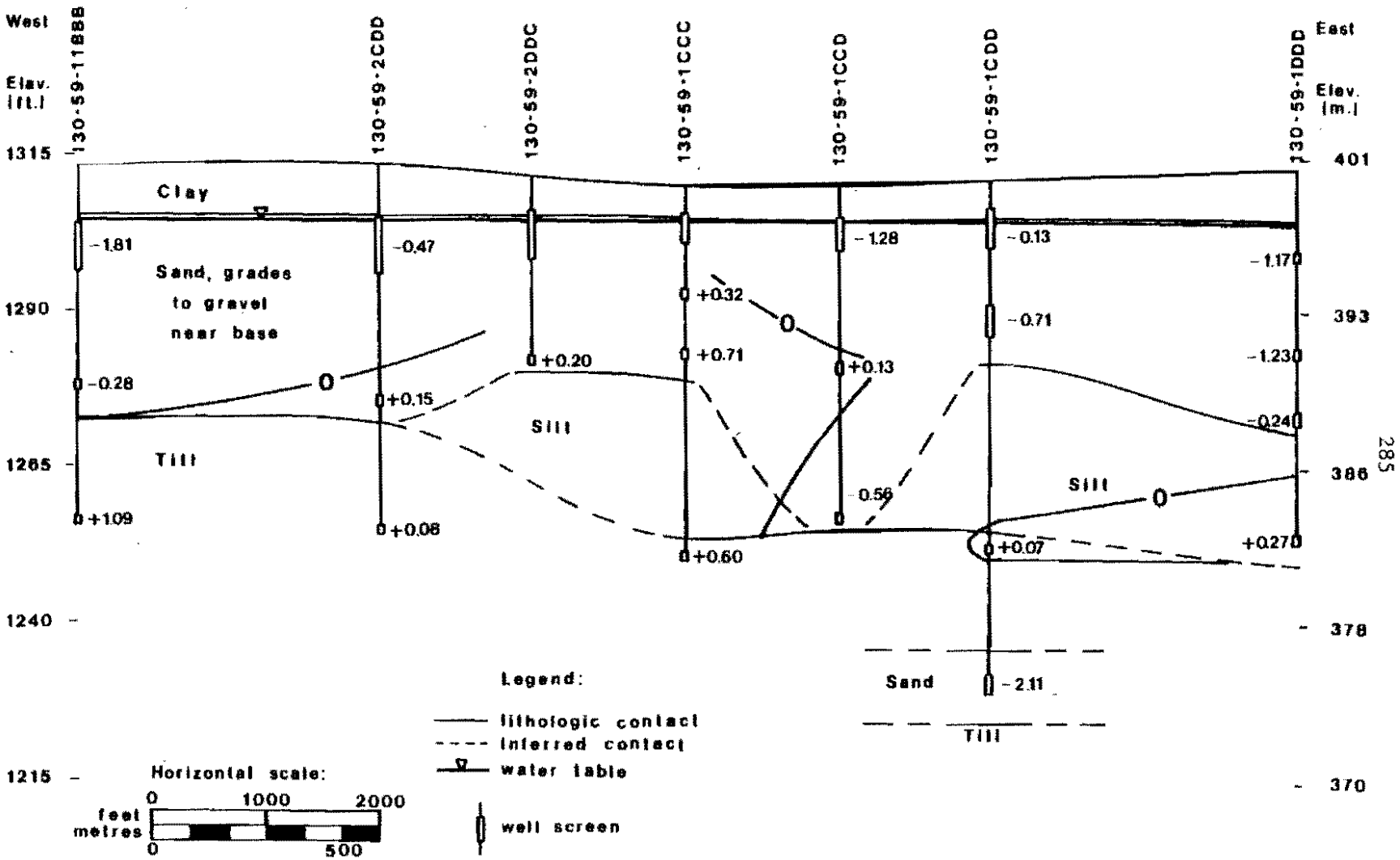

West
Elev. (ft.)
East
Elev. (m.)
130-59-11BBB
130-59-2CDD
130-59-2DDC
130-59-1CCC
130-59-1CCD
130-59-1CDD
130-59-1DDD
1315
1290
1265
1240
1215
401
393
386
378
370
Clay
Sand, grades to gravel near base
Till
Silt
Sand
Till
-1.81
-0.47
-1.28
-0.13
-1.170
+0.32
-0.71
-0.28
+0.15
+0.20
+0.71
+0.13
-1.230
-0.240
+1.09
+0.08
+0.60
0.56
+0.07
+0.270
-2.11
Legend:
lithologic contact
inferred contact
water table
well screen
Horizontal scale:
feet
metres
0
1000
2000
0
500
285

Figure 71. Dolomite saturation along the east-west traverse (October-November, 1983).

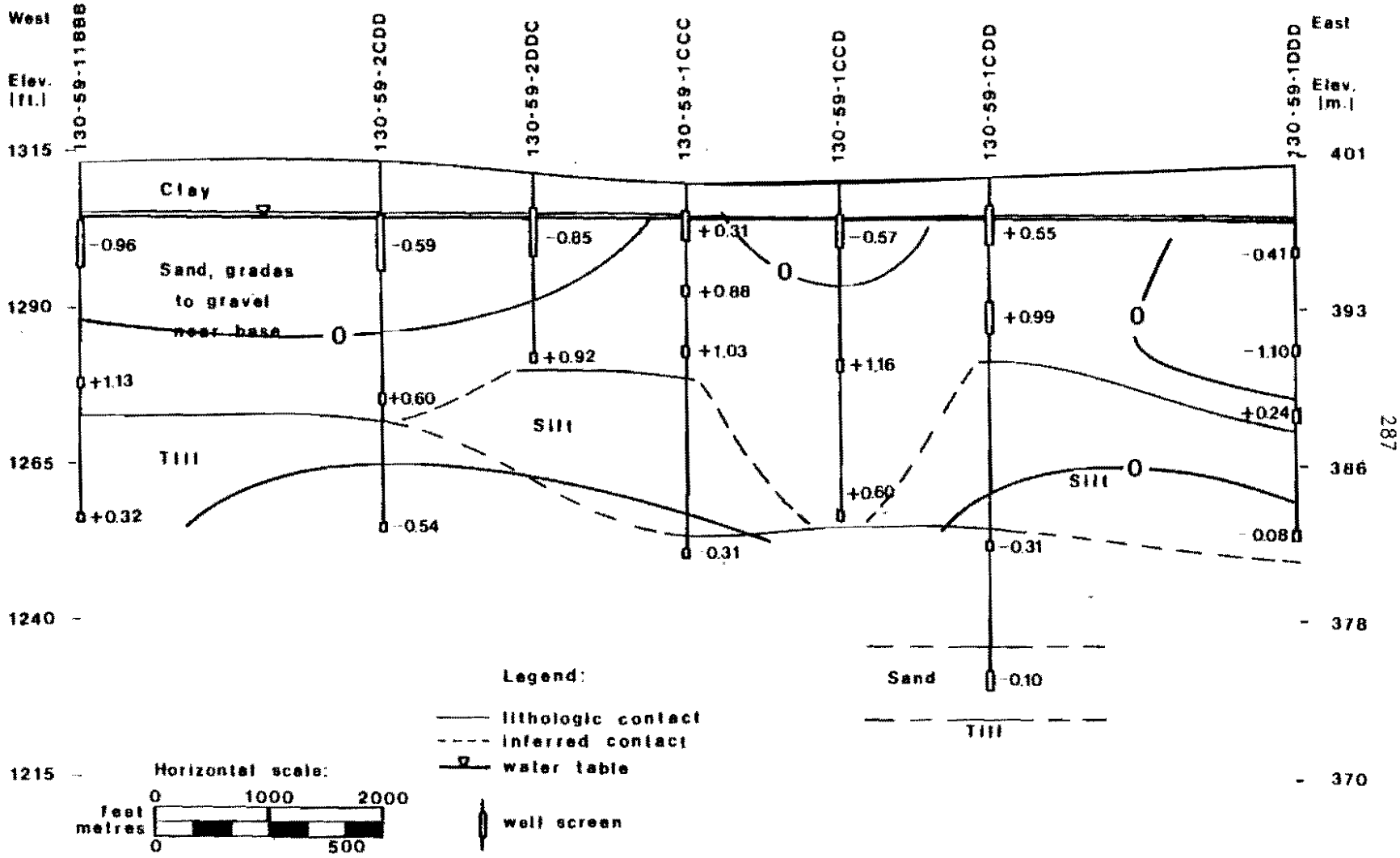

West
East
Elev. (ft.)
Elev. (m.)
130-59-11BBB
130-59-2CDD
130-59-2DDC
130-59-1CCC
130-59-1CCD
130-59-1CDD
130-59-1DDD
1315
1290
1265
1240
1215
401
393
386
378
370
Clay
Sand, grades to gravel near base
Silt
Till
-0.96
-0.59
-0.85
+0.31
-0.57
+0.55
-0.410
+0.88
+0.99
+1.13
+0.60
+0.92
+1.03
+1.16
-1.100
+0.24
+0.32
-0.54
-0.31
+0.60
-0.31
-0.08
-0.10
Sand
Till
Legend:
lithologic contact
inferred contact
water table
well screen
Horizontal scale:
feet
metres
0
1000
2000
500
287

Figure 72. Dolomite saturation along the east-west traverse (February, 1984).

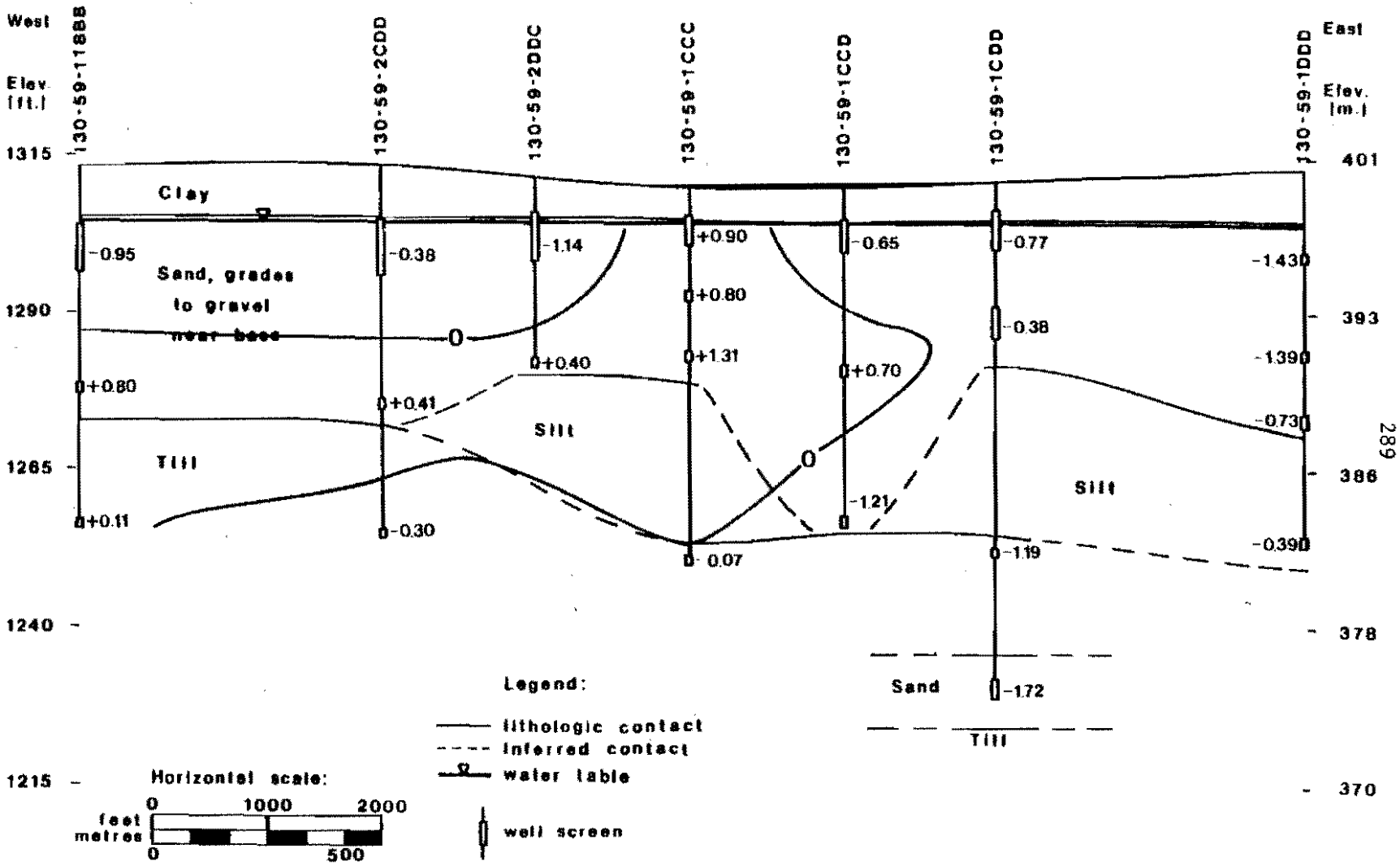

West
East
Elev. (ft.)
Elev. (m.)
1315
1290
1265
1240
1215
401
393
386
378
370
289
130-59-11BBB
130-59-2CDD
130-59-2DDC
130-59-1CCC
130-59-1CCD
130-59-1CDD
130-59-1DDD
Clay
Sand, grades to gravel near base
Till
Silt
Sand
Till
-0.95
-0.38
-1.14
+0.90
+0.80
+1.31
-0.65
+0.70
-0.77
-0.38
-1.43
-1.39
-0.73
-0.39
+0.80
+0.11
+0.41
+0.40
-0.30
0.07
-1.21
-1.19
-1.72
Legend:
lithologic contact
inferred contact
water table
well screen
Horizontal scale:
feet
metres
0
1000
2000
500

Figure 73. Dolomite saturation along the east-west traverse (April, 1984).

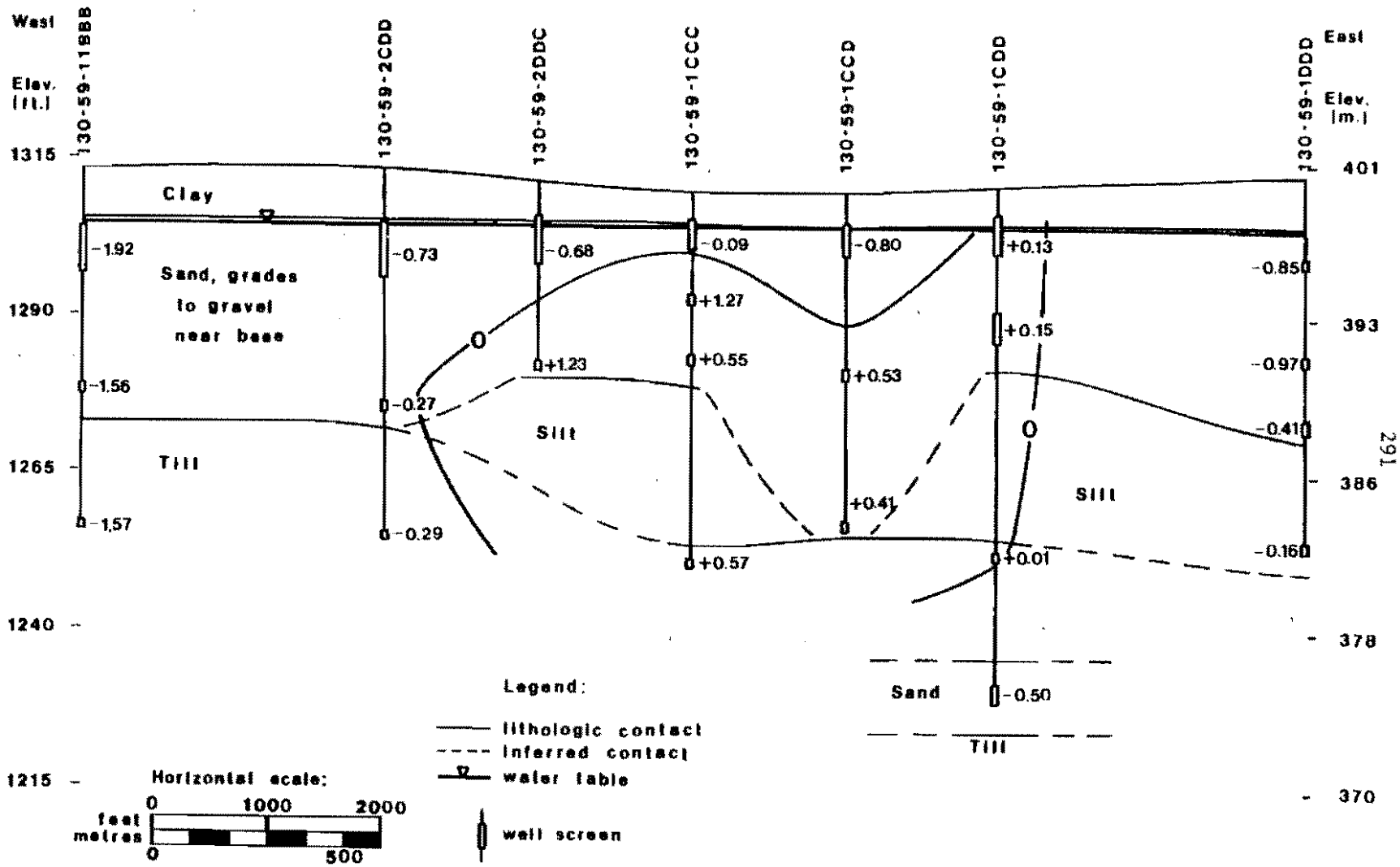

West
East
Elev. (ft.)
Elev. (m.)
130-59-11BBB
130-59-2CDD
130-59-2DDC
130-59-1CCC
130-59-1CCD
130-59-1CDD
130-59-1DDD
1315
1290
1265
1240
1215
401
393
386
378
370
Clay
Sand, grades to gravel near base
Till
Silt
Sand
-1.92
-1.56
-1.57
-0.73
-0.27
-0.29
-0.68
+1.23
-0.09
+1.27
+0.55
+0.57
-0.80
+0.53
+0.41
+0.13
+0.15
+0.01
-0.50
-0.850
-0.970
-0.410
-0.160
Legend:
lithologic contact
inferred contact
water table
well screen
Horizontal scale:
feet
metres
0
1000
2000
500
291

Figure 74. Siderite saturation along the east-west traverse (September, 1983).

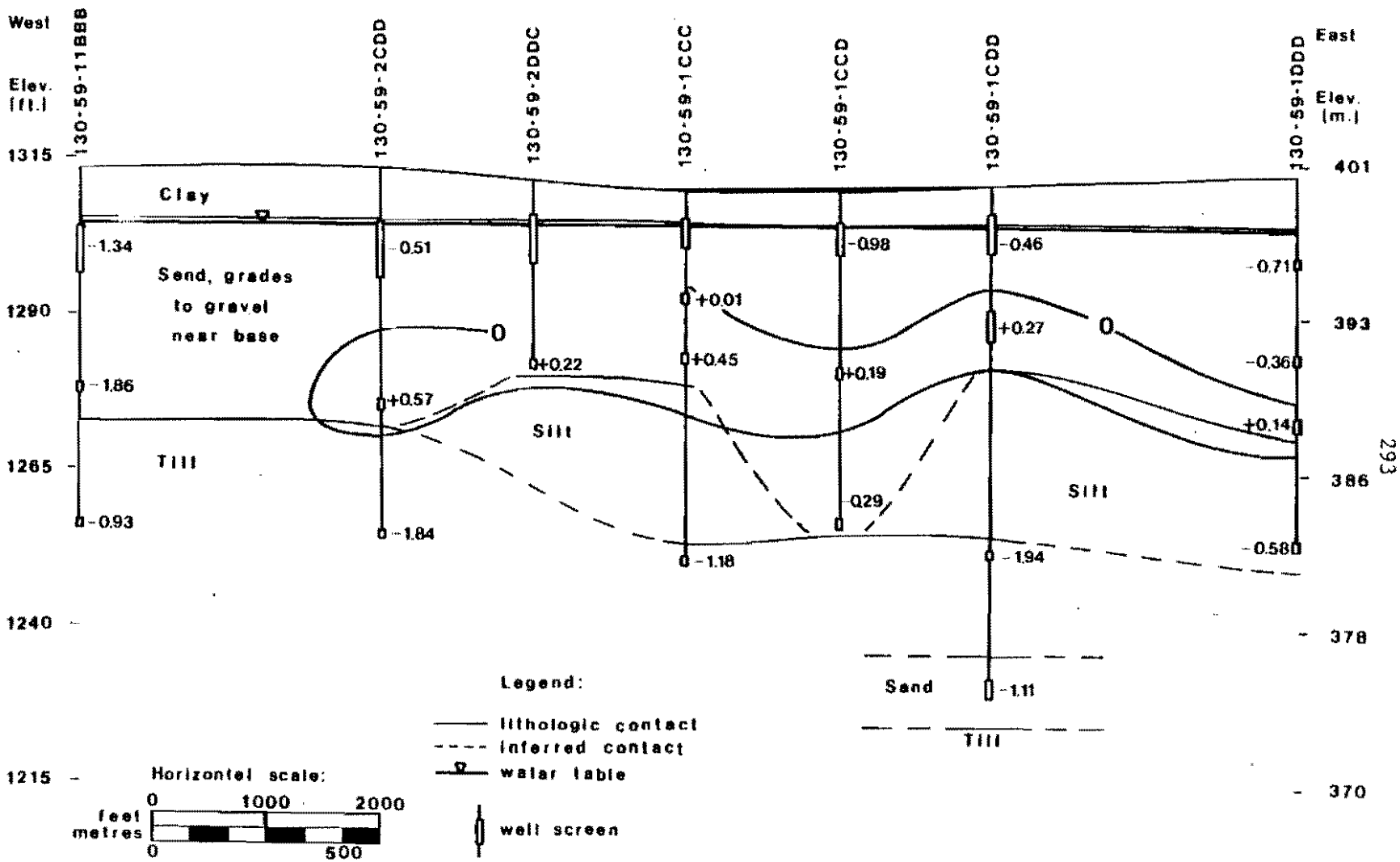

West
East
Elev. (ft.)
Elev. (m.)
130-59-11BBB
130-59-2CDD
130-59-2DDC
130-59-1CCC
130-59-1CCD
130-59-1CDD
130-59-1DDD
1315
1290
1265
1240
1215
401
393
386
378
370
Clay
Sand, grades to gravel near base
Silt
Till
Sand
Till
-1.34
0.51
-0.98
-0.46
-0.710
-1.86
+0.57
+0.22
+0.01
+0.45
+0.19
+0.27
-0.360
+0.14
-0.93
-1.84
-1.18
0.29
-1.94
-0.580
-1.11
0
0
293
Legend:
lithologic contact
inferred contact
water table
well screen
Horizontal scale:
feet
metres
0
1000
2000
500

Figure 75. Siderite saturation along the east-west traverse (October-November, 1983).

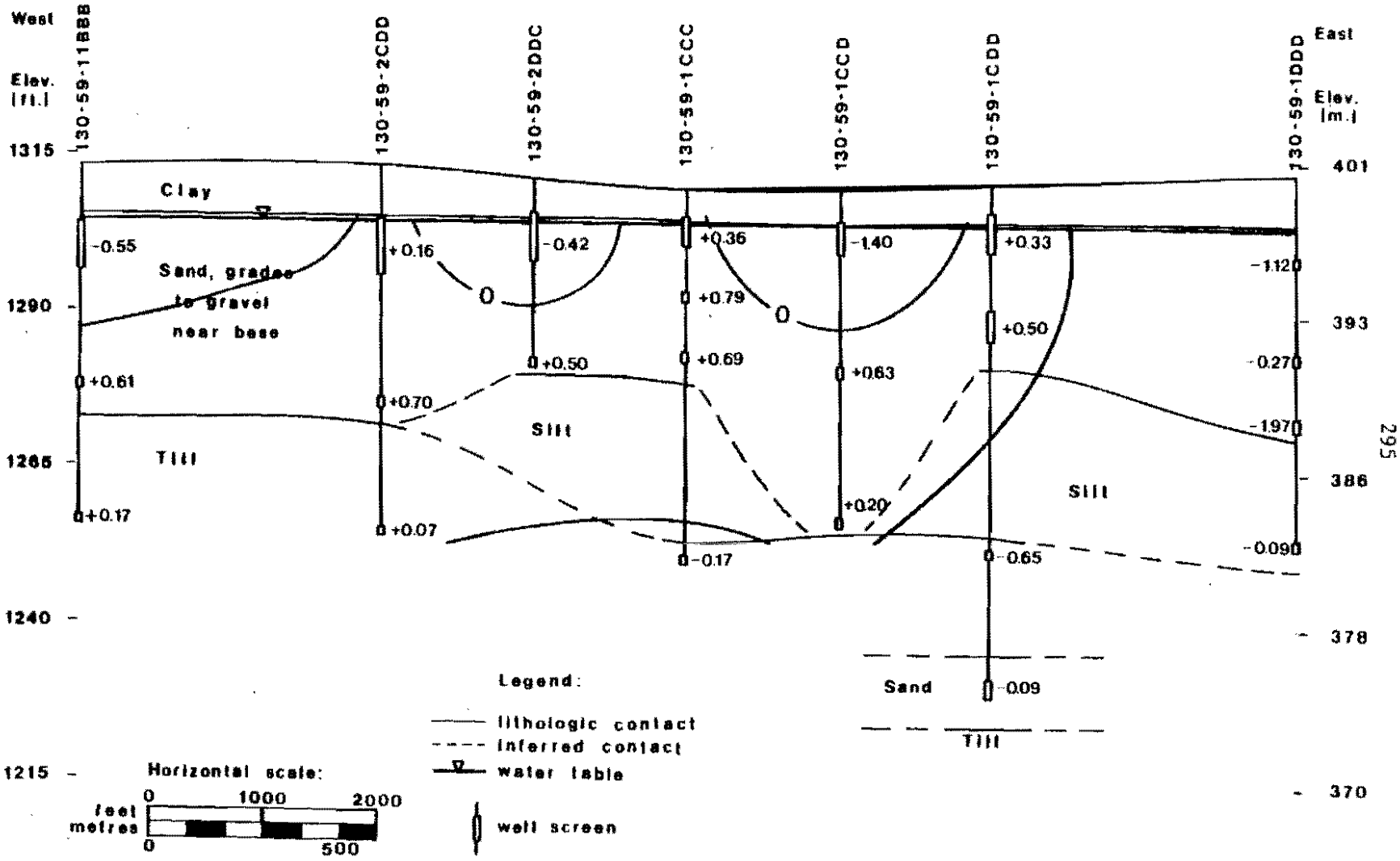

West
East
Elev. (ft.)
Elev. (m.)
1315
1290
1265
1240
1215
401
393
386
378
370
130-59-11BBB
130-59-2CDD
130-59-2DDC
130-59-1CCC
130-59-1CCD
130-59-1CDD
130-59-1DDD
Clay
Sand, grades to gravel near base
Till
Silt
Sand
Till
-0.55
+0.61
+0.17
+0.16
+0.70
+0.07
-0.42
+0.50
+0.36
+0.79
+0.69
-0.17
-1.40
+0.63
+0.20
+0.33
+0.50
-0.65
-0.09
-1.120
-0.270
-1.970
-0.090
Legend:
lithologic contact
inferred contact
water table
well screen
Horizontal scale:
feet
metres
0
1000
2000
500

Figure 76. Siderite saturation along the east-west traverse (February, 1984).

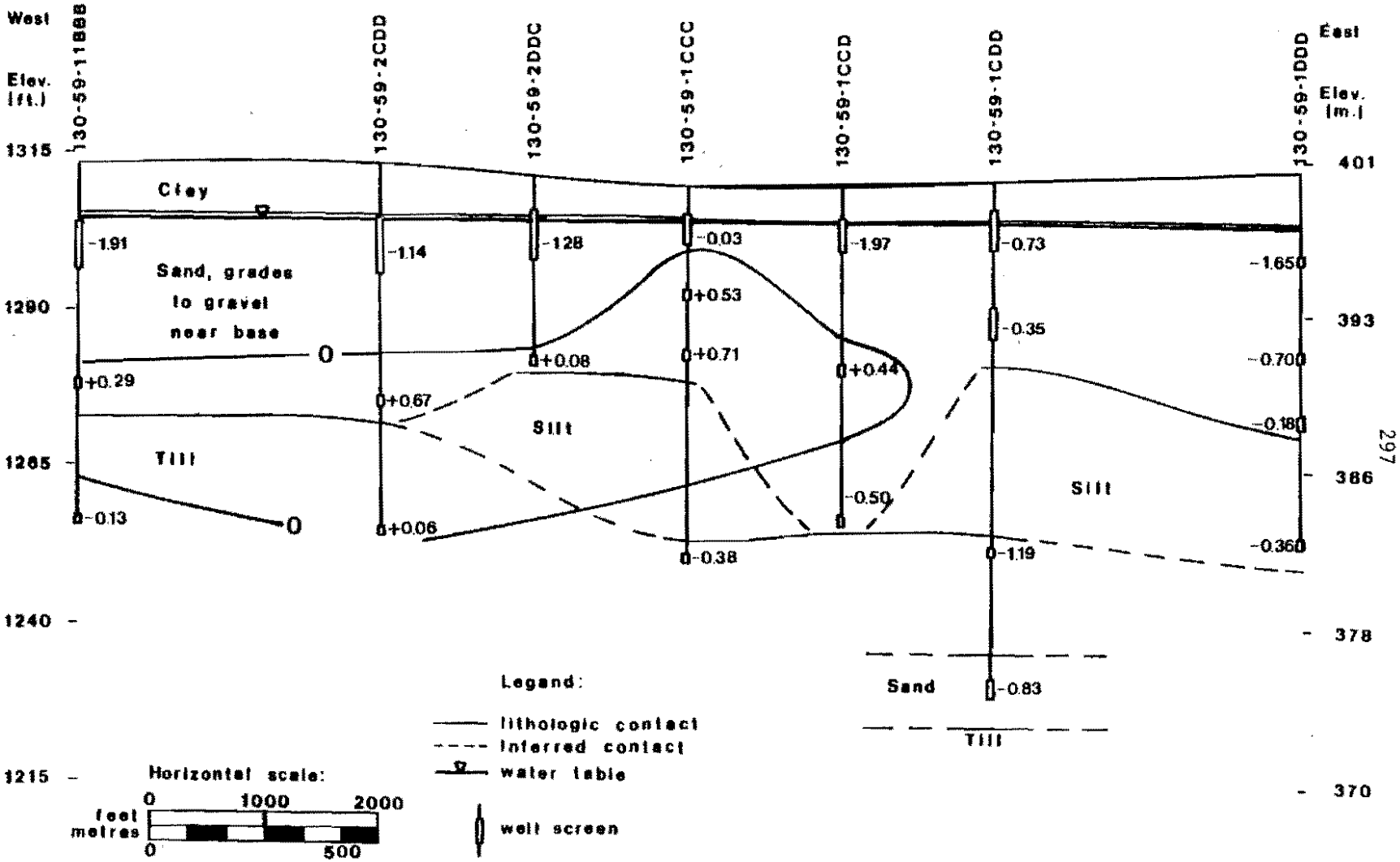

West
East
Elev. (ft.)
Elev. (m.)
130-59-11BBB
130-59-2CDD
130-59-2DDC
130-59-1CCC
130-59-1CCD
130-59-1CDD
130-59-1DDD
1315
1290
1265
1240
1215
401
393
386
378
370
Clay
Sand, grades to gravel near base
Silt
Till
Sand
Till
-1.91
-1.14
-1.28
-0.03
-1.97
-0.73
-1.650
0+0.53
-0.35
0+0.29
0
0+0.08
0+0.71
0+0.44
-0.700
0+0.67
-0.180
0-0.13
0
0+0.06
-0.50
0-0.38
0-1.19
-0.360
0-0.83
Legend:
lithologic contact
inferred contact
water table
well screen
Horizontal scale:
0
1000
2000
feet
metres
0
500
297

Figure 77. Siderite saturation along the east-west traverse (April, 1984).

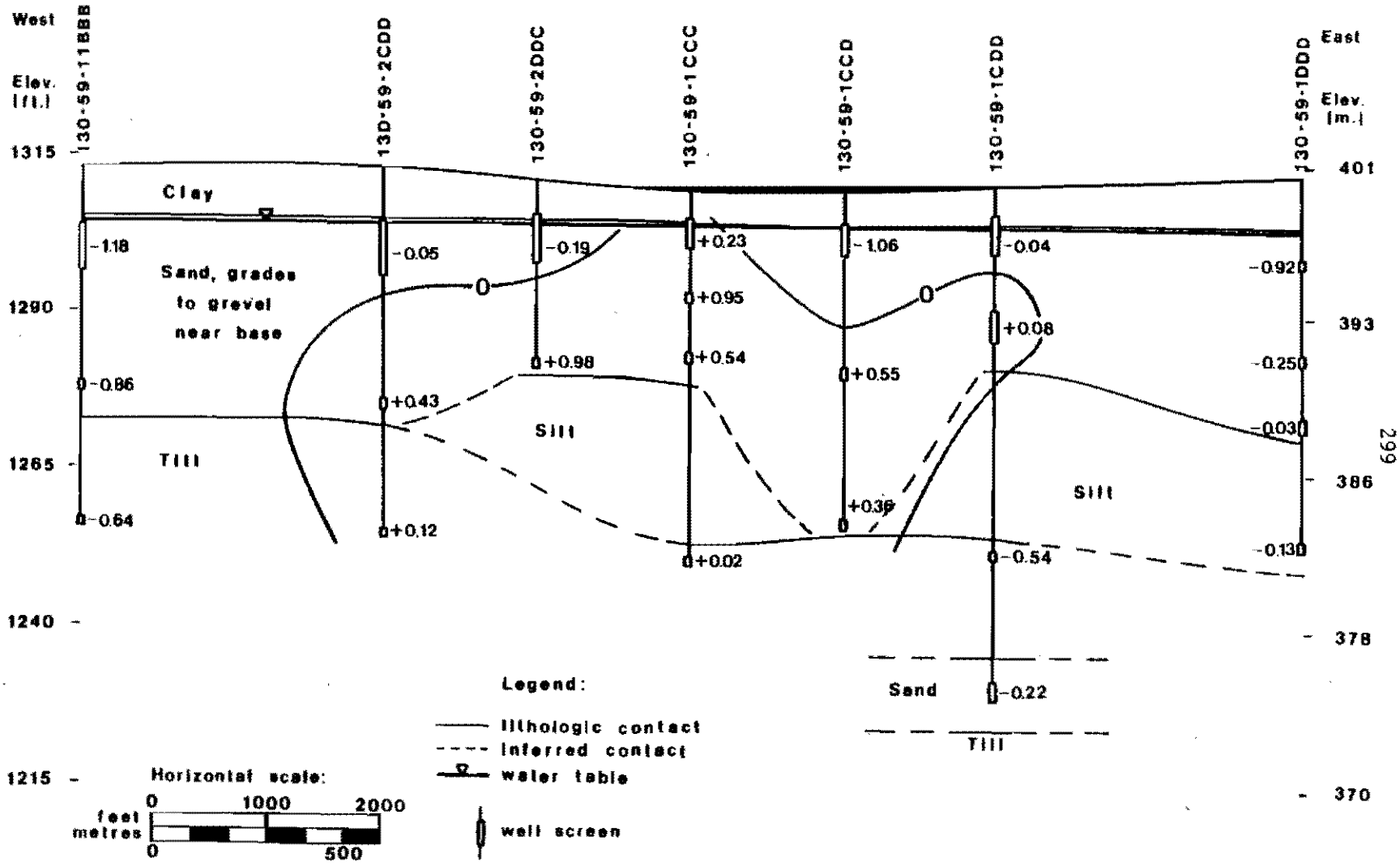

West
East
Elev. (ft.)
Elev. (m.)
1315
1290
1265
1240
1215
401
393
386
378
370
130-59-11BBB
130-59-2CDD
130-59-2DDC
130-59-1CCC
130-59-1CCD
130-59-1CDD
130-59-1DDD
Clay
Sand, grades to gravel near base
Till
Silt
Sand
Till
-1.18
-0.86
-0.64
-0.05
+0.43
+0.12
-0.19
+0.98
+0.23
+0.95
+0.54
+0.02
-1.06
+0.55
+0.39
-0.04
+0.08
-0.54
-0.22
-0.920
-0.250
-0.030
-0.130
Legend:
lithologic contact
inferred contact
water table
well screen
Horizontal scale:
feet
metres
0
1000
2000
500
299

Figure 78. Gypsum saturation along the east-west traverse (September, 1983).

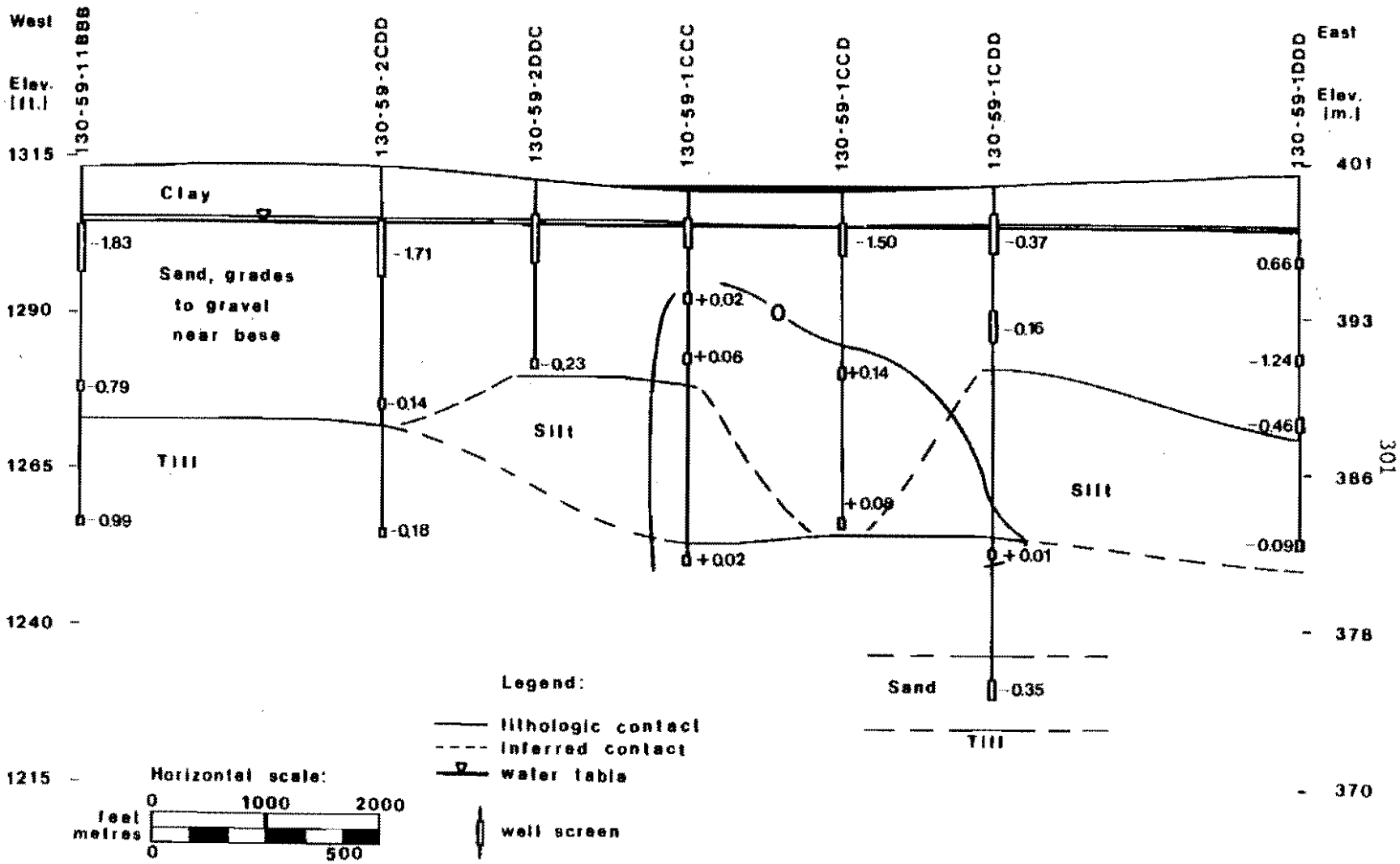

West
East
Elev. (ft.)
Elev. (m.)
130-59-11BBB
130-59-2CDD
130-59-2DDC
130-59-1CCC
130-59-1CCD
130-59-1CDD
130-59-1DDD
1315
1290
1265
1240
1215
401
393
386
378
370
Clay
Sand, grades to gravel near base
Till
Silt
Sand
Till
-1.83
-0.79
-0.99
-1.71
-0.14
-0.18
-0.23
+0.02
+0.06
+0.02
-1.50
+0.14
+0.09
-0.37
-0.16
+0.01
-0.35
0.660
-1.240
-0.460
-0.090
Legend:
lithologic contact
inferred contact
water table
well screen
Horizontal scale:
feet
metres
0
1000
2000
500

Figure 79. Gypsum saturation along the east-west traverse (October-November, 1983).

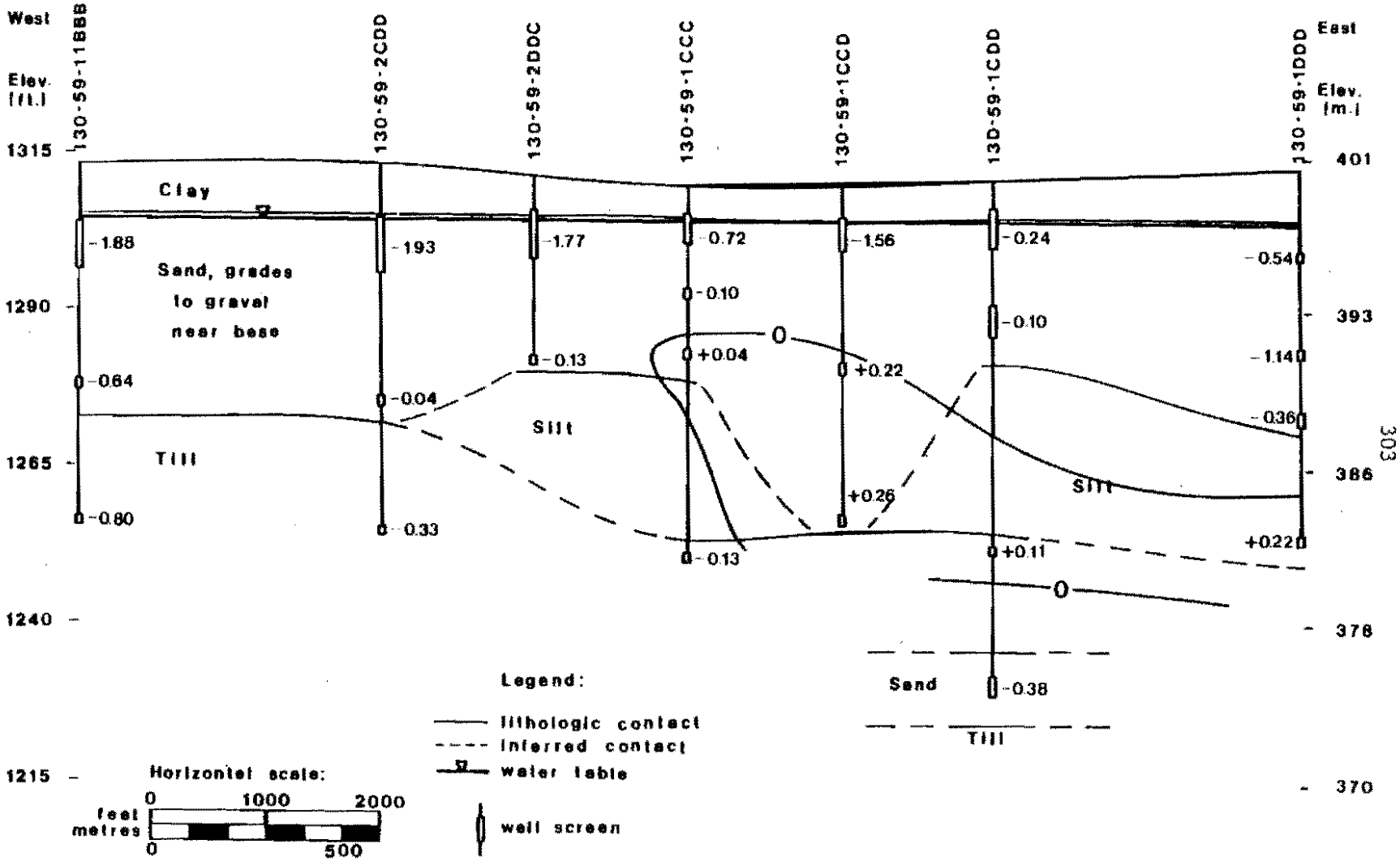

West
East
Elev. (ft.)
Elev. (m.)
130-59-11BBB
130-59-2CDD
130-59-2DDC
130-59-1CCC
130-59-1CCD
130-59-1CDD
130-59-1DDD
1315
1290
1265
1240
1215
401
393
386
378
370
Clay
Sand, grades to gravel near base
Till
Silt
Sand
Till
-1.88
-0.64
-0.80
-1.93
-0.04
-0.33
-1.77
-0.13
-0.72
-0.10
+0.04
-0.13
-1.56
+0.22
+0.26
-0.24
-0.10
+0.11
-0.54
-1.14
-0.36
+0.22
-0.38
0
0
0
Legend:
lithologic contact
inferred contact
water table
well screen
Horizontal scale:
feet
metres
0
1000
2000
500
303

Figure 80. Gypsum saturation along the east-west traverse (February, 1984).

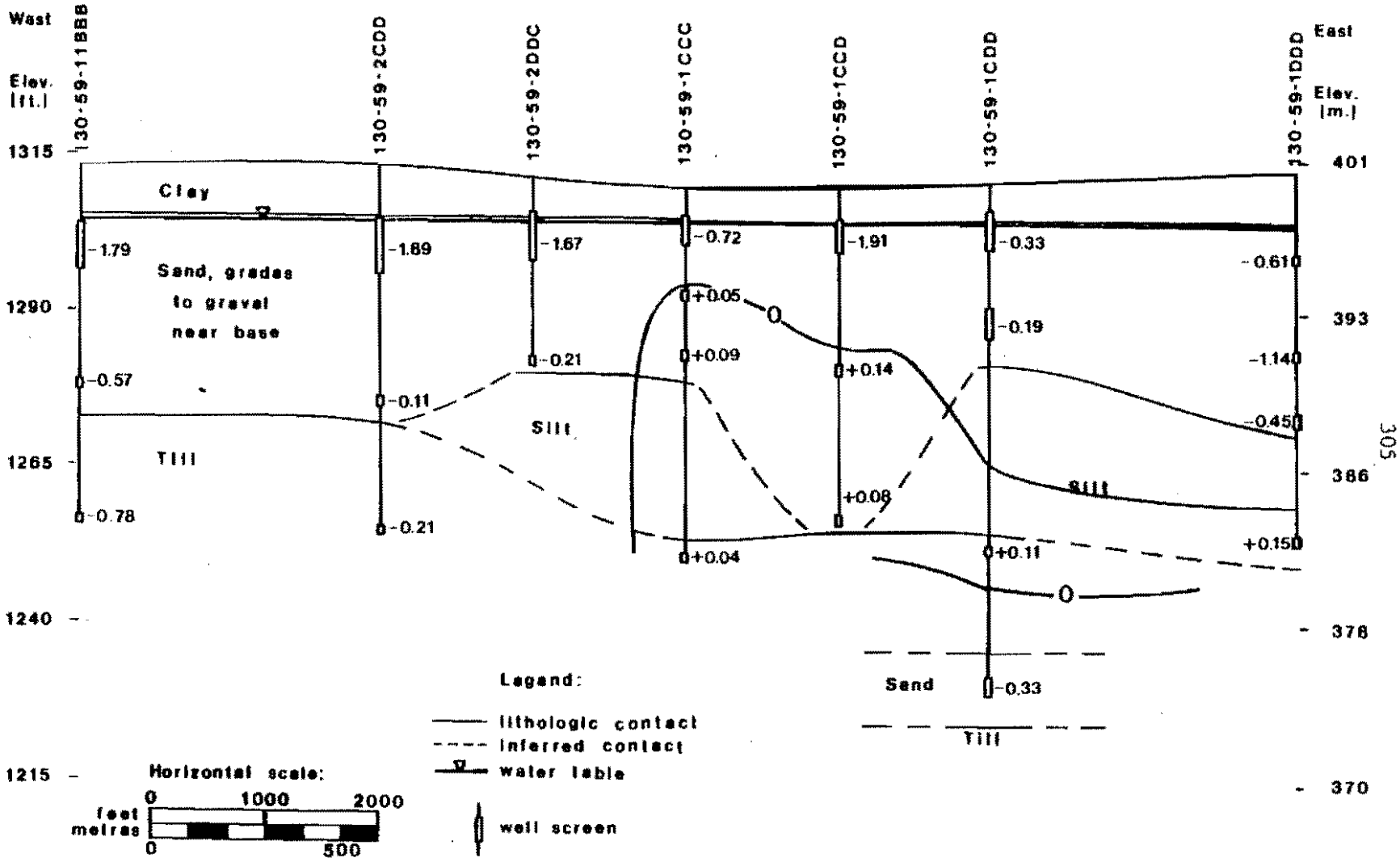

West
East
Elev. (ft.)
Elev. (m.)
130-59-11BBB
130-59-2CDD
130-59-2DDC
130-59-1CCC
130-59-1CCD
130-59-1CDD
130-59-1DDD
1315
1290
1265
1240
1215
401
393
386
378
370
Clay
Sand, grades to gravel near base
Silt
Till
Sand
Till
-1.79
-0.57
-0.78
-1.89
-0.11
-0.21
-1.67
-0.21
-0.72
+0.05
+0.09
+0.04
-1.91
+0.14
+0.08
-0.33
-0.19
+0.11
-0.610
-1.140
-0.450
+0.150
0
Legend:
lithologic contact
inferred contact
water table
well screen
Horizontal scale:
feet
metres
0
1000
2000
500

Figure 81. Gypsum saturation along the east-west traverse (April, 1984).

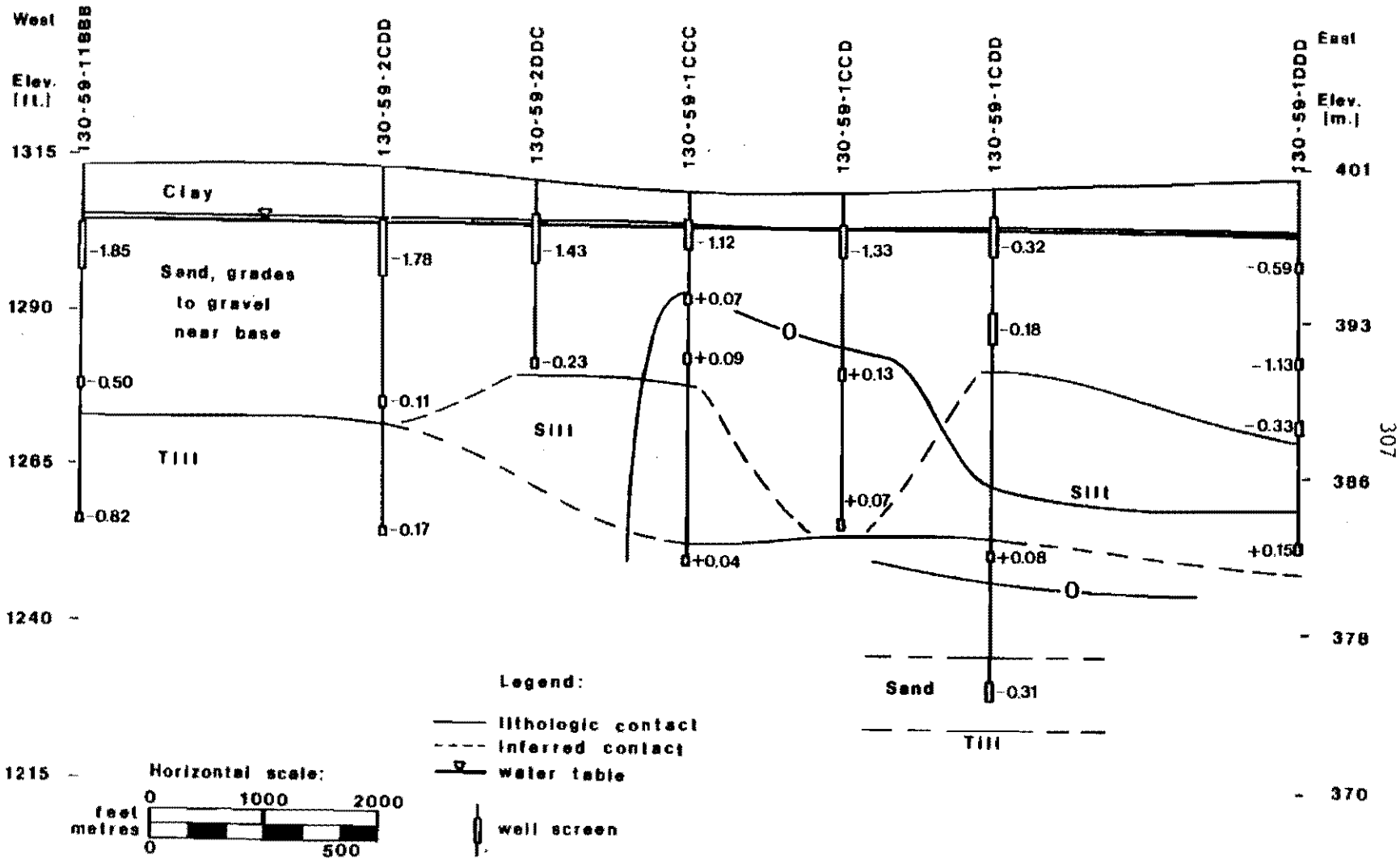
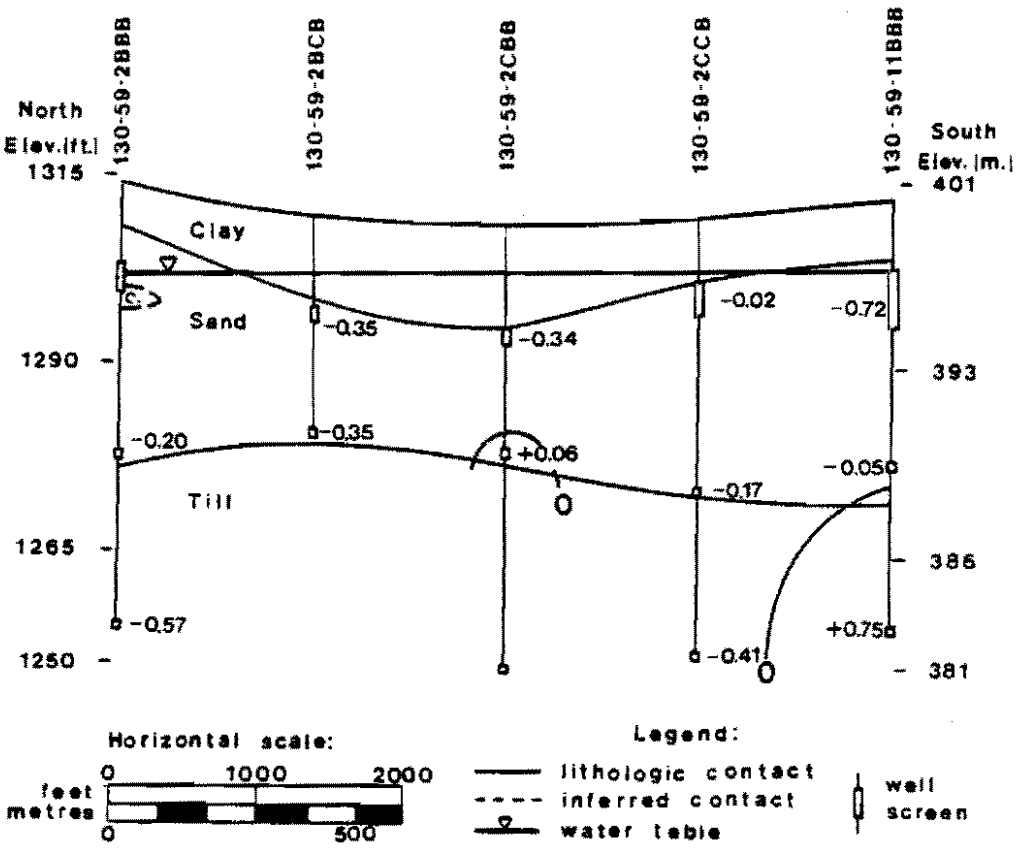

West
East
Elev. [ft.]
Elev. [m.]
1315
1290
1265
1240
1215
401
393
386
378
370
130-59-11BBB
130-59-2CDD
130-59-2DDC
130-59-1CCC
130-59-1CCD
130-59-1CDD
130-59-1DDD
Clay
Sand, grades to gravel near base
Till
Silt
Sand
Till
-1.85
-0.50
-0.82
-1.78
-0.11
-0.17
-1.43
-0.23
+0.07
+0.09
+0.04
-1.12
+0.13
+0.07
-1.33
-0.18
+0.08
-0.32
-0.31
-0.590
-1.130
-0.330
+0.150
0
Legend:
lithologic contact
inferred contact
water table
well screen
Horizontal scale:
feet
metres
0
1000
2000
500

Figure 82. Calcite saturation along the north-south traverse (September, 1983).

Figure 83. Dolomite saturation along the north-south traverse (September, 1983).


North
Elev.(ft.)
1315
1290
1265
1250
South
Elev.(m.)
401
393
386
381
130-59-2BBB
130-59-2BCB
130-59-2CBB
130-59-2CCB
130-59-11BBB
Clay
Sand
Till
-0.35
-0.34
-0.02
-0.72
-0.20
-0.35
+0.06
-0.17
-0.050
-0.57
-0.41
+0.75
Horizontal scale:
feet
metres
0
1000
2000
500
Legend:
lithologic contact
inferred contact
water table
well screen

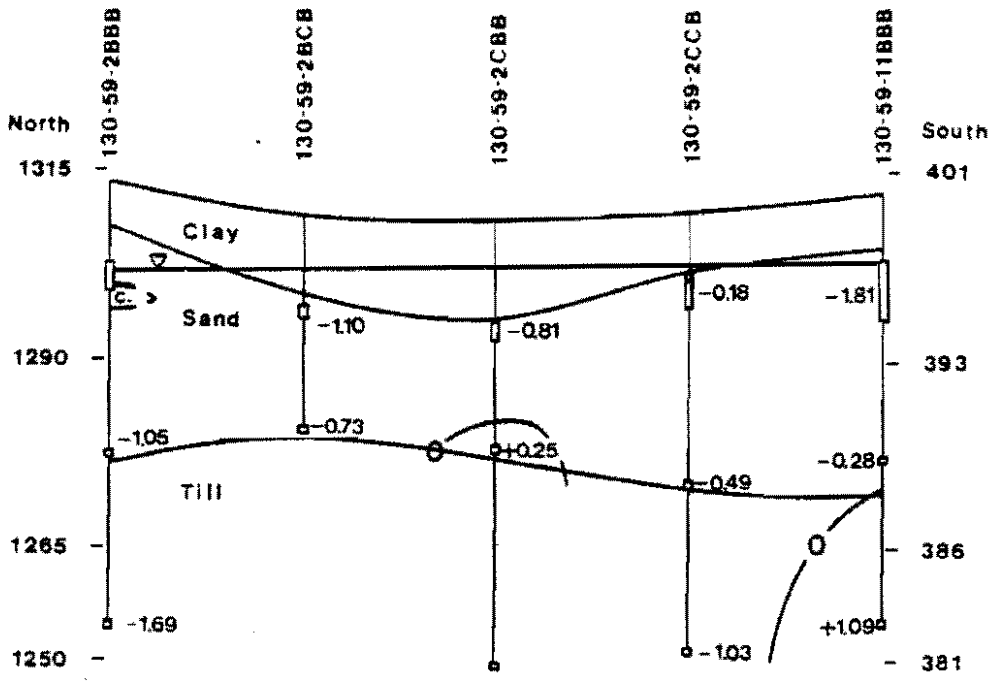
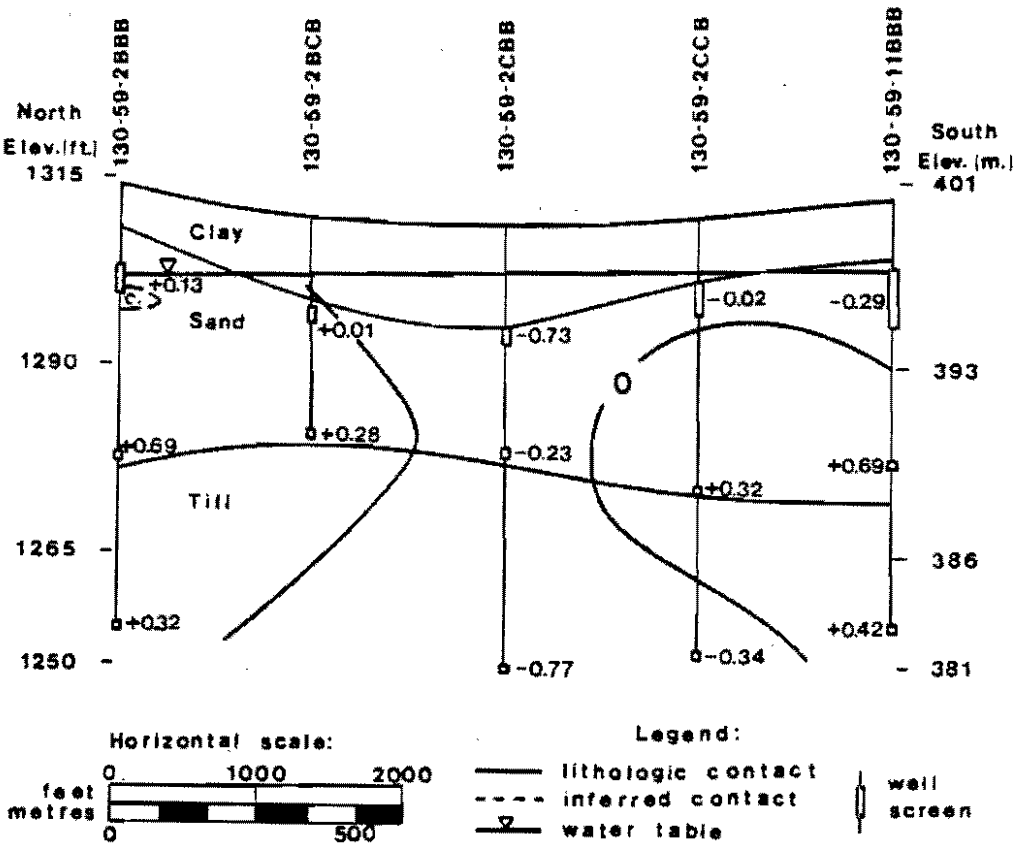

North
1315
1290
1265
1250
South
401
393
386
381
130-59-2BBB
130-59-2BCB
130-59-2CBB
130-59-2CCB
130-59-11BBB
Clay
Sand
Till
-1.10
-0.81
-0.18
-1.81
-1.05
-0.73
+0.25
-0.49
-0.28
-1.69
-1.03
+1.09

Figure 84. Calcite saturation along the north-south traverse (October-November, 1983).

Figure 85. Dolomite saturation along the north-south traverse (October-November, 1983).


North
Elev.(ft.)
1315
1290
1265
1250
130-59-2BBB
130-59-2BCB
130-59-2CBB
130-59-2CCB
130-59-11BBB
South
Elev. (m.)
401
393
386
381
Clay
Sand
Till
+0.13
+0.01
-0.73
-0.02
-0.29
+0.69
+0.28
-0.23
+0.32
+0.69
+0.32
+0.42
-0.77
-0.34
Horizontal scale:
feet
metres
0
1000
2000
500
Legend:
lithologic contact
inferred contact
water table
well screen

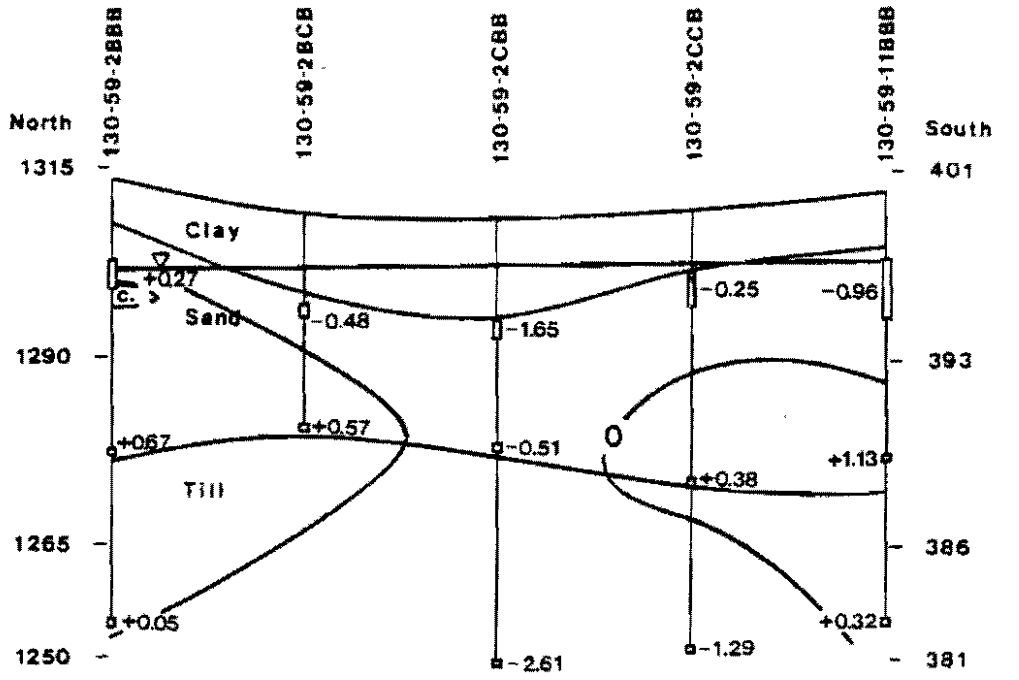
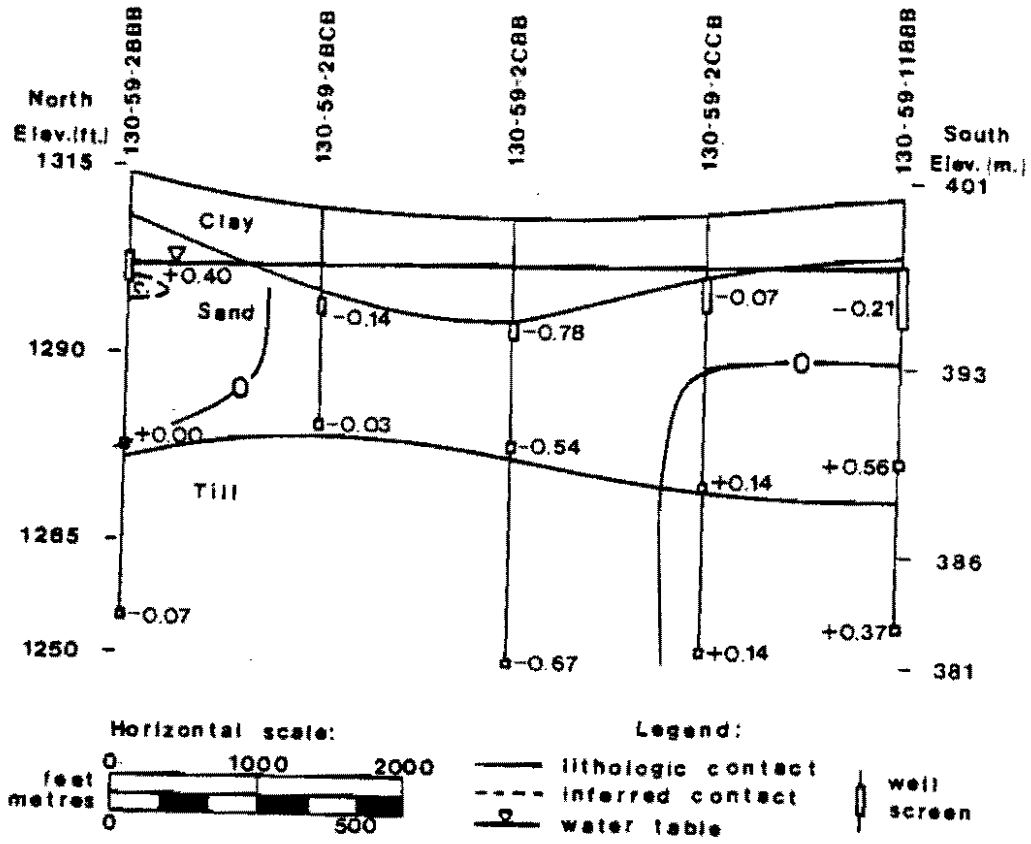

North
1315
1290
1265
1250
130-59-2BBB
130-59-2BCB
130-59-2CBB
130-59-2CCB
130-59-11BBB
South
401
393
386
381
Clay
Sand
Till
+0.27
-0.48
-1.65
-0.25
-0.96
+0.67
+0.57
-0.51
+0.38
+1.13
+0.05
+0.32
-2.61
-1.29

Figure 86. Calcite saturation along the north-south traverse (February, 1984).

Figure 87. Dolomite saturation along the north-south traverse (February, 1984).


North
Elev.(ft.)
1315
1290
1285
1250
130-59-2BBB
130-59-2BCB
130-59-2CBB
130-59-2CCB
130-59-11BBB
South
Elev.(m.)
401
393
386
381
Clay
Sand
Till
+0.40
-0.14
-0.78
-0.07
-0.21
+0.00
-0.03
-0.54
+0.14
+0.56
-0.07
-0.67
+0.14
+0.37
Horizontal scale:
feet
metres
0
1000
2000
500
Legend:
lithologic contact
inferred contact
water table
well screen

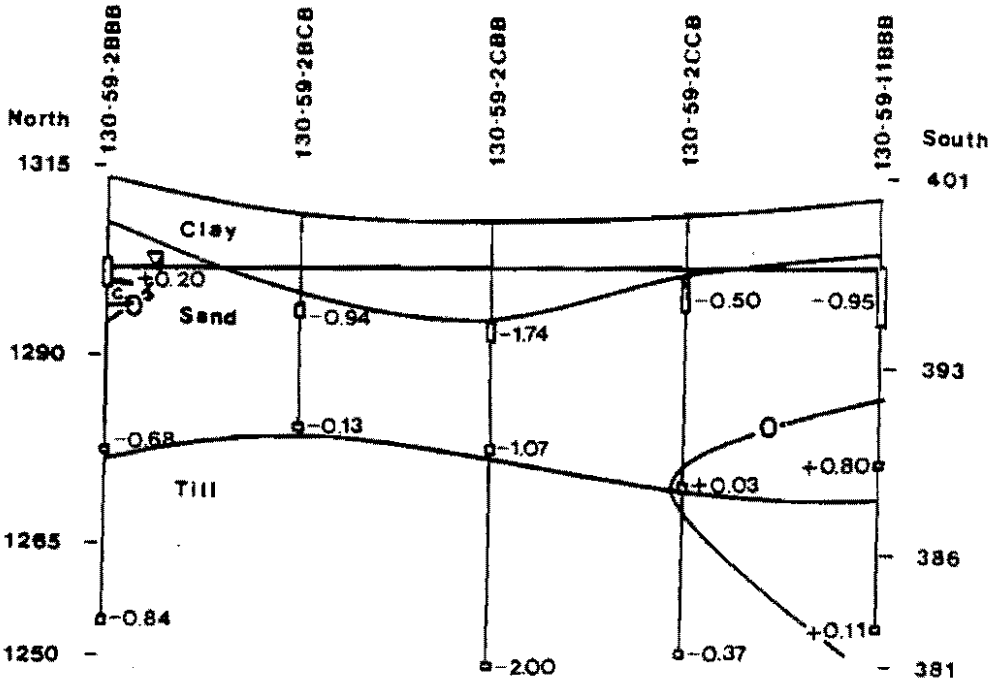
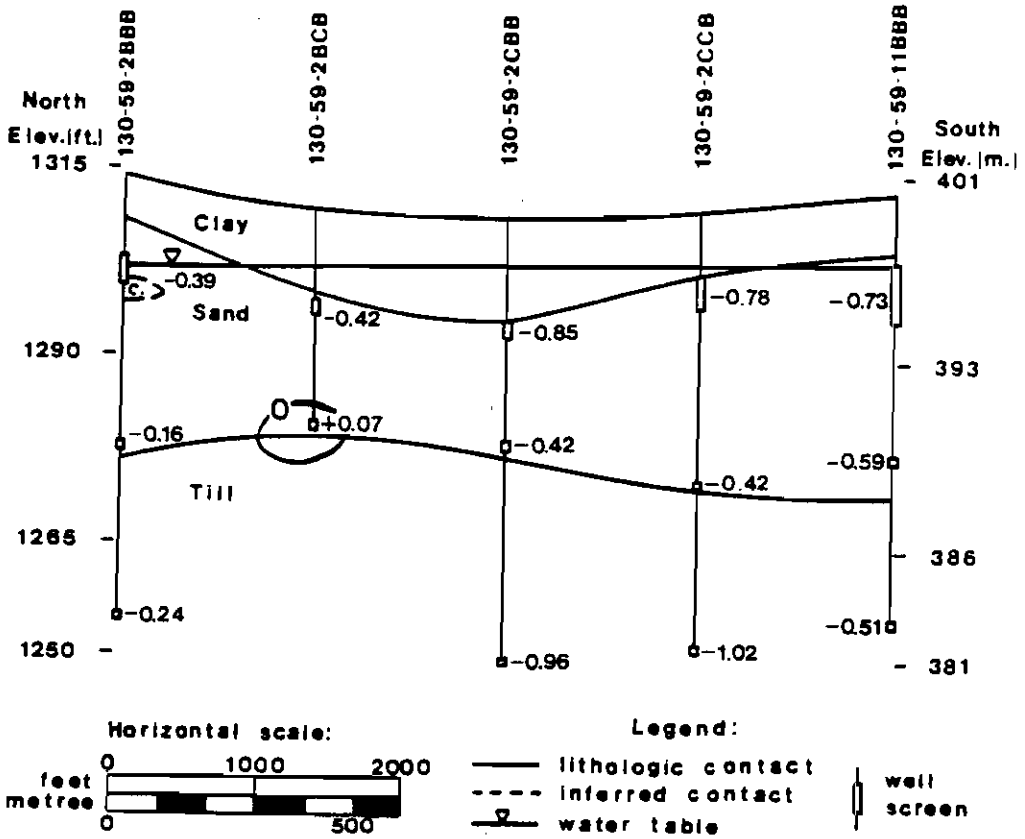

North
1315
1290
1265
1250
130-59-2BBB
130-59-2BCB
130-59-2CBB
130-59-2CCB
130-59-11BBB
South
401
393
386
381
Clay
Sand
Till
+0.20
-0.94
-1.74
-0.50
-0.95
-0.68
-0.13
-1.07
+0.03
+0.80
-0.84
-2.00
-0.37
+0.11

Figure 88. Calcite saturation along the north-south traverse (April, 1984).

Figure 89. Dolomite saturation along the north-south traverse (April, 1984).


North
Elev.(ft.)
1315
1290
1265
1250
130-59-2BBB
130-59-2BCB
130-59-2CBB
130-59-2CCB
130-59-11BBB
South
Elev.(m.)
401
393
386
381
Clay
Sand
Till
-0.39
-0.42
-0.85
-0.78
-0.73
-0.16
+0.07
-0.42
-0.42
-0.59
-0.24
-0.96
-1.02
-0.51
Horizontal scale:
feet
metres
0
1000
2000
500
Legend:
lithologic contact
inferred contact
water table
well screen

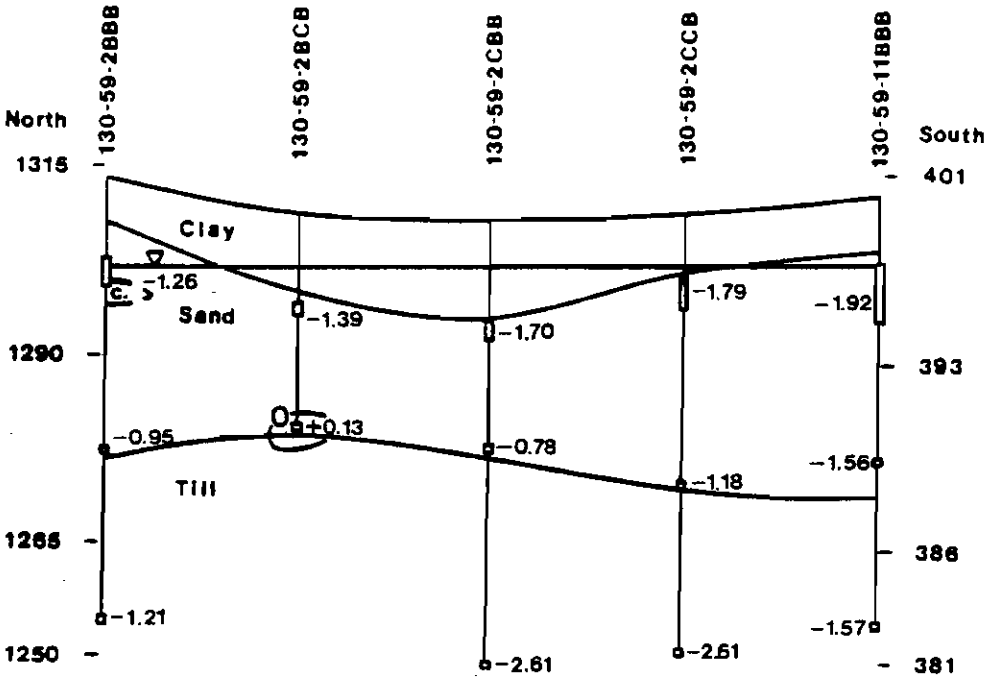
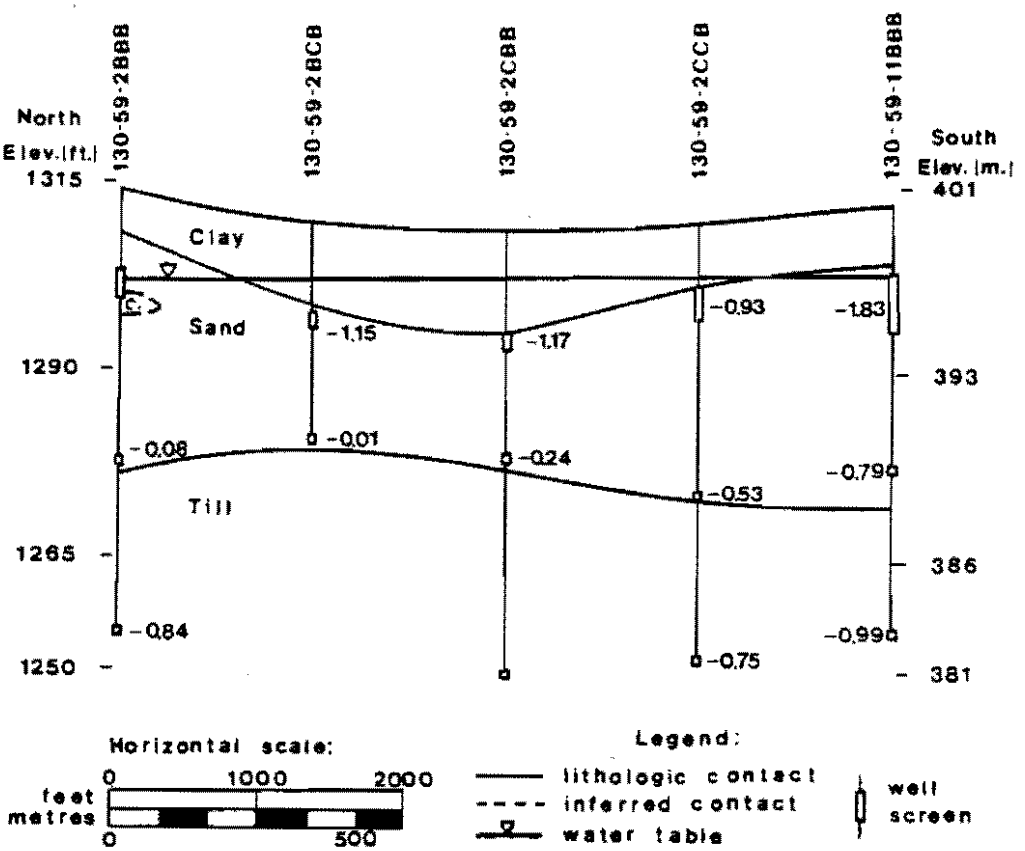

North
1315
1290
1265
1250
130-59-2BBB
130-59-2BCB
130-59-2CBB
130-59-2CCB
130-59-11BBB
South
401
393
386
381
Clay
Sand
Till
-1.26
-1.39
-1.70
-1.79
-1.92
-0.95
+0.13
-0.78
-1.18
-1.56
-1.21
-2.61
-2.61
-1.57

Figure 90. Gypsum saturation along the north-south traverse (September, 1983).

Figure 91. Siderite saturation along the north-south traverse (September, 1983).


North
Elev.(ft.)
1315
1290
1265
1250
South
Elev.(m.)
401
393
386
381
130-59-2BBB
130-59-2BCB
130-59-2CBB
130-59-2CCB
130-59-11BBB
Clay
Sand
Till
-1.15
-1.17
-0.93
-1.83
-0.06
-0.01
-0.24
-0.53
-0.79
-0.84
-0.75
-0.99
Horizontal scale:
feet
metres
0
1000
2000
500
Legend:
lithologic contact
inferred contact
water table
well screen

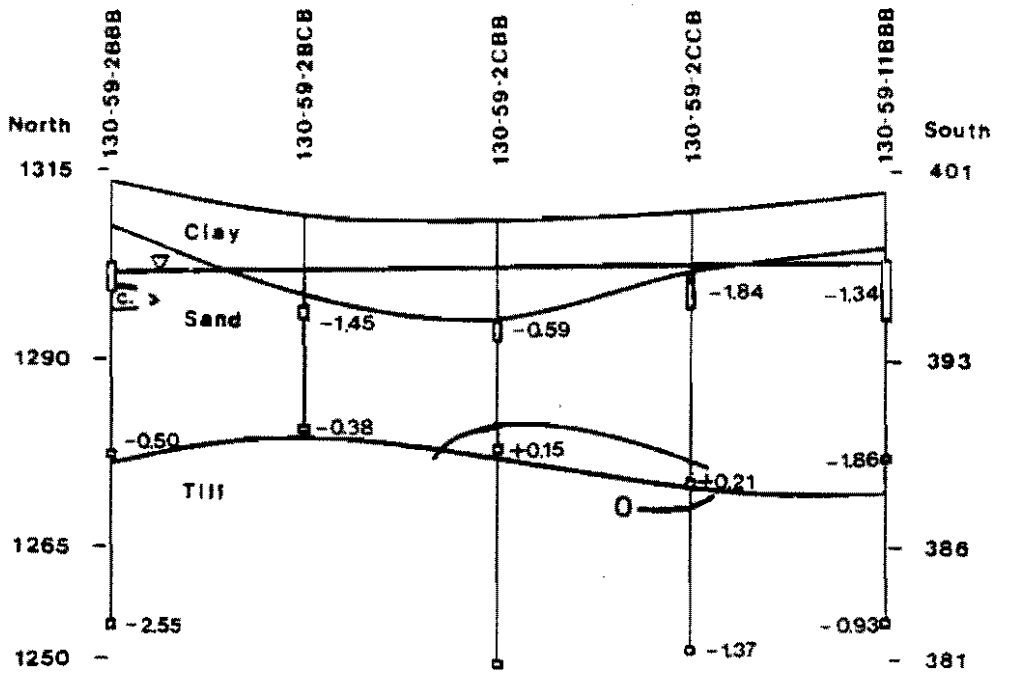
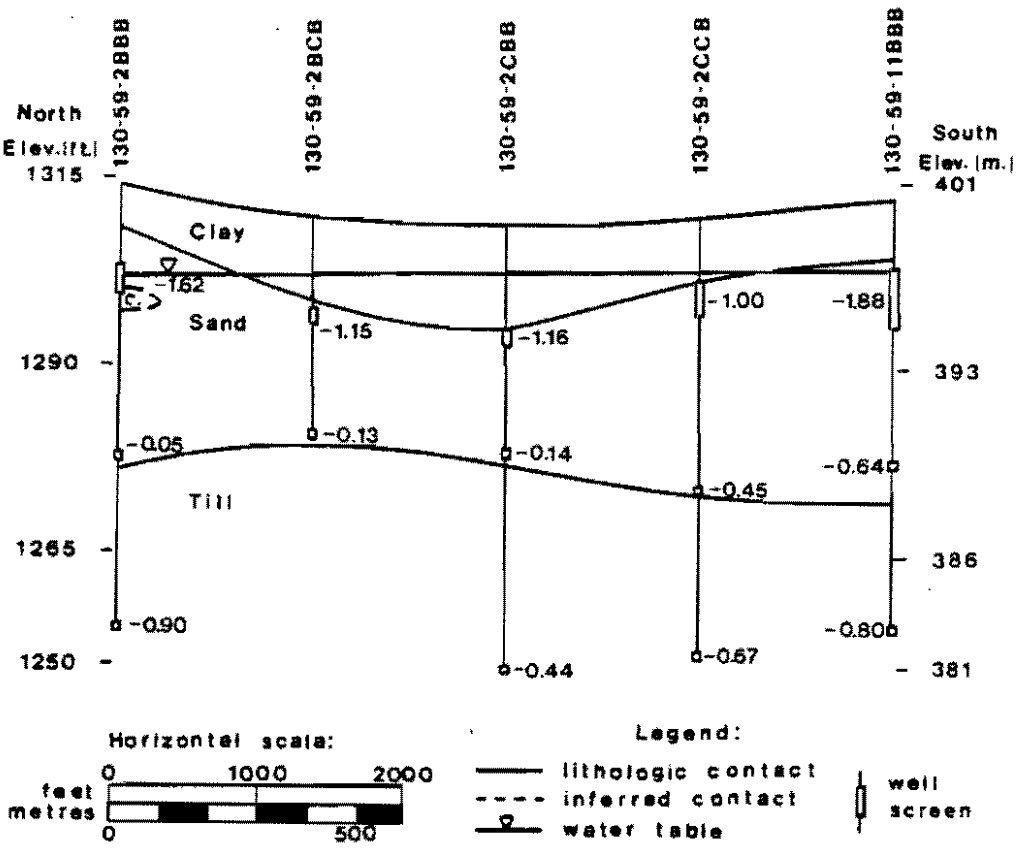

North
1315
1290
1265
1250
South
401
393
386
381
130-59-2BBB
130-59-2BCB
130-59-2CBB
130-59-2CCB
130-59-11BBB
Clay
Sand
Till
-1.45
-0.59
-1.84
-1.34
-0.50
-0.38
+0.15
+0.21
-1.86
0
-2.55
-1.37
-0.93

Figure 92. Gypsum saturation along the north-south traverse (October-November, 1983).

Figure 93. Siderite saturation along the north-south traverse (October-November, 1983).


North
Elev.(ft.)
1315
1290
1265
1250
South
Elev. (m.)
401
393
386
381
130-59-2BBB
130-59-2BCB
130-59-2CBB
130-59-2CCB
130-59-11BBB
Clay
Sand
Till
-1.62
-1.15
-1.16
-1.00
-1.88
-0.05
-0.13
-0.14
-0.45
-0.64
-0.90
-0.44
-0.67
-0.80
Horizontal scale:
feet
metres
0
1000
2000
500
Legend:
lithologic contact
inferred contact
water table
well screen

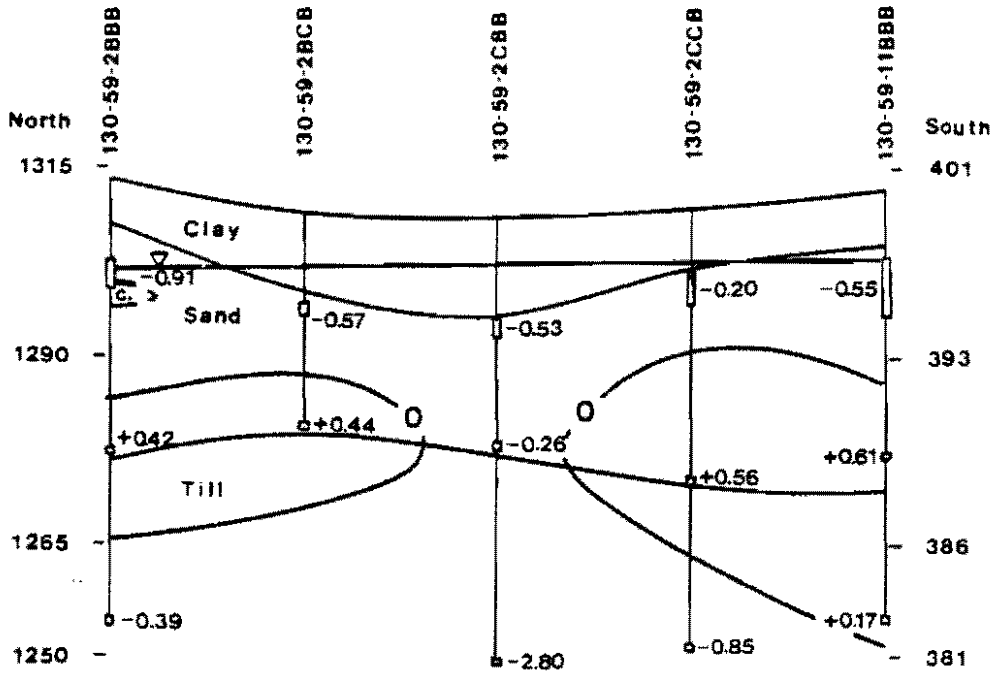
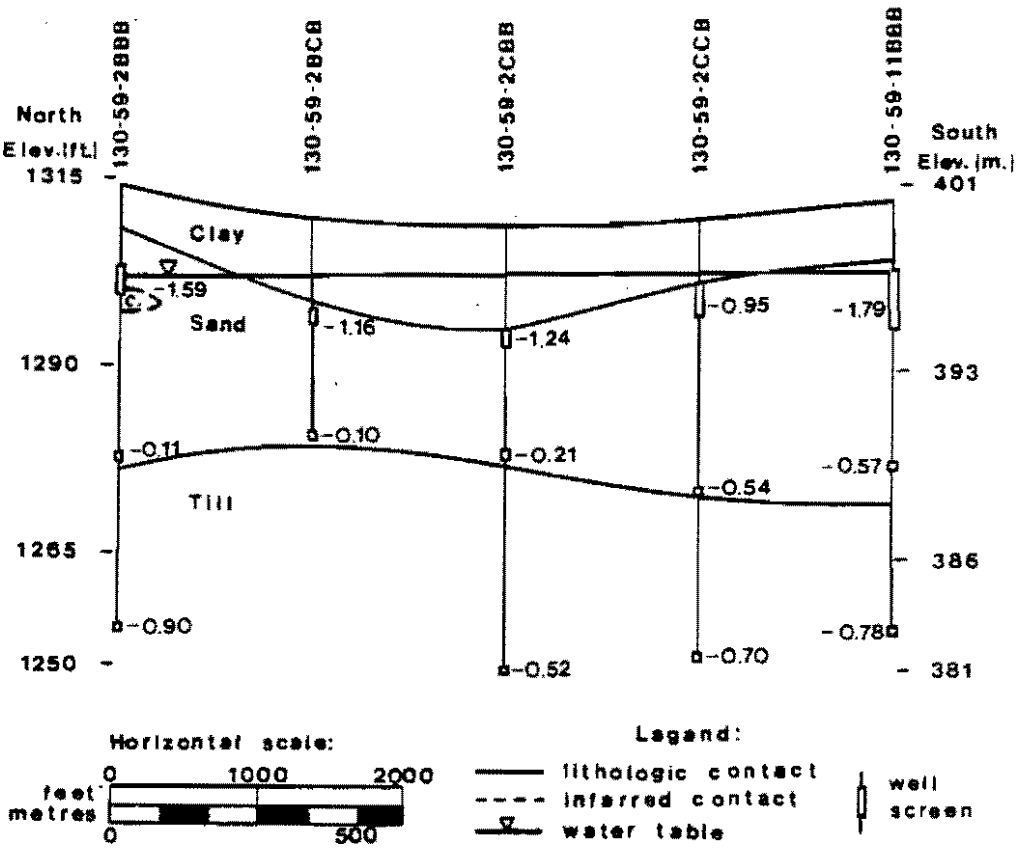

North
1315
1290
1265
1250
South
401
393
386
381
130-59-2BBB
130-59-2BCB
130-59-2CBB
130-59-2CCB
130-59-11BBB
Clay
Sand
Till
-0.91
-0.57
-0.53
-0.20
-0.55
+0.42
+0.44
-0.26
+0.56
+0.61
-0.39
-2.80
-0.85
+0.17

Figure 94. Gypsum saturation along the north-south traverse (February, 1984).

Figure 95. Siderite saturation along the north-south traverse (February, 1984).


North
Elev.(ft.)
1315
1290
1265
1250
130-59-2BBB
130-59-2BCB
130-59-2CBB
130-59-2CCB
130-59-11BBB
South
Elev.(m.)
401
393
386
381
Clay
Sand
Till
-1.59
-1.16
-1.24
-0.95
-1.79
-0.11
-0.10
-0.21
-0.54
-0.57
-0.90
-0.52
-0.70
-0.78
Horizontal scale:
feet
metres
0
1000
2000
500
Legend:
lithologic contact
inferred contact
water table
well screen

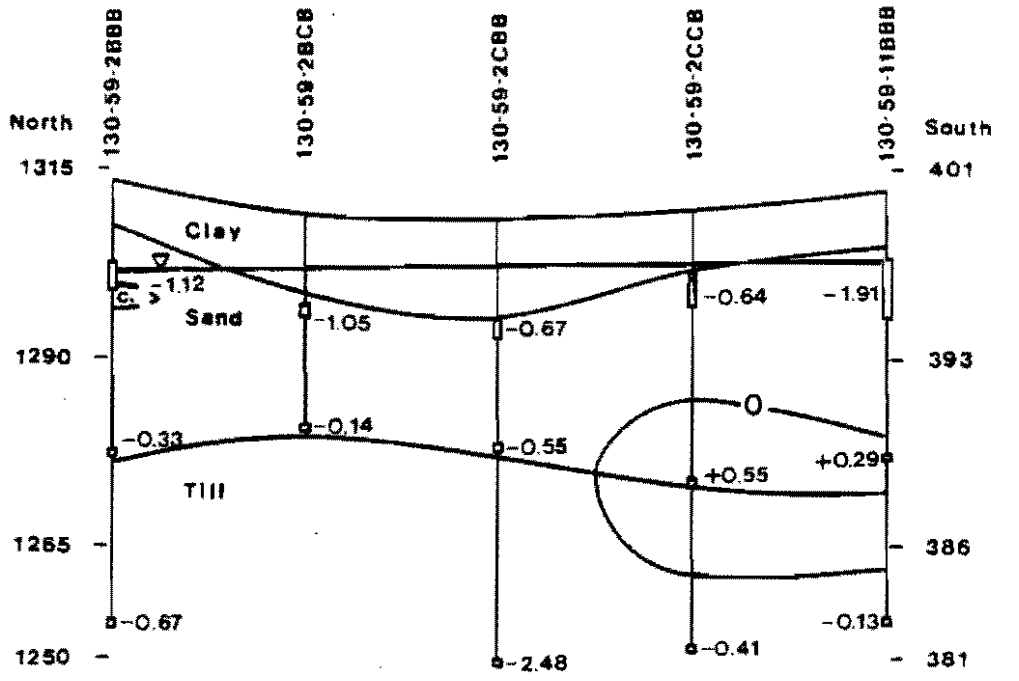
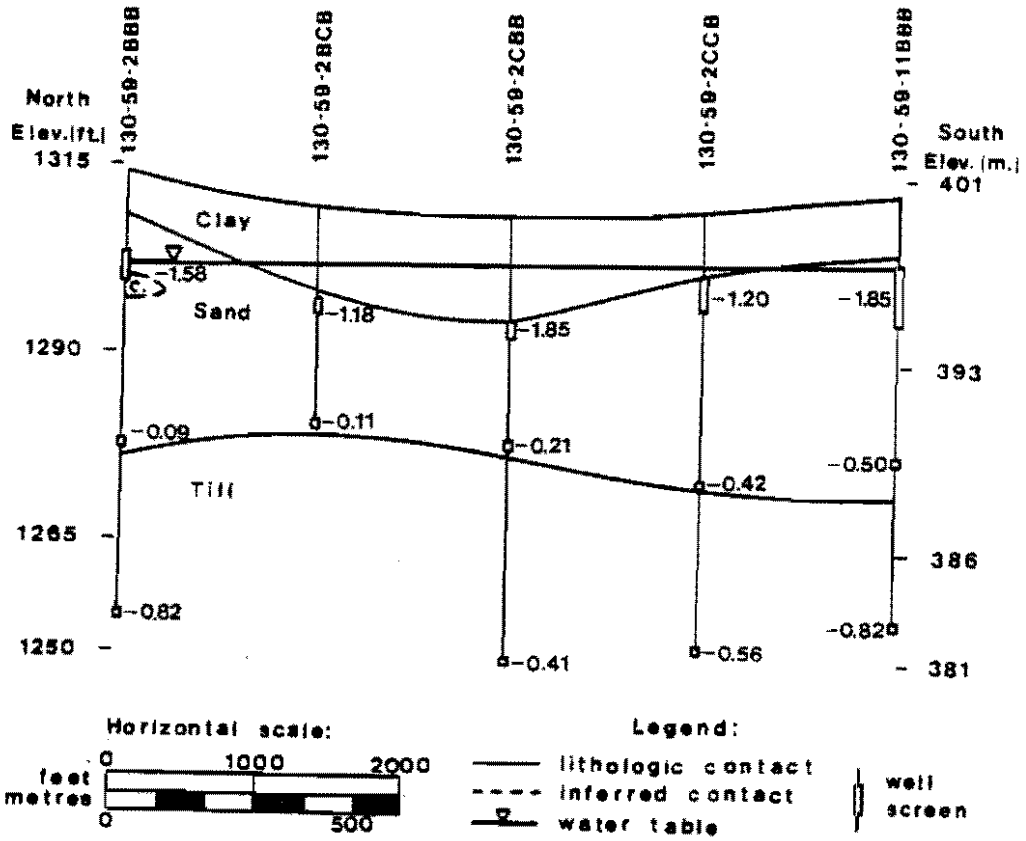
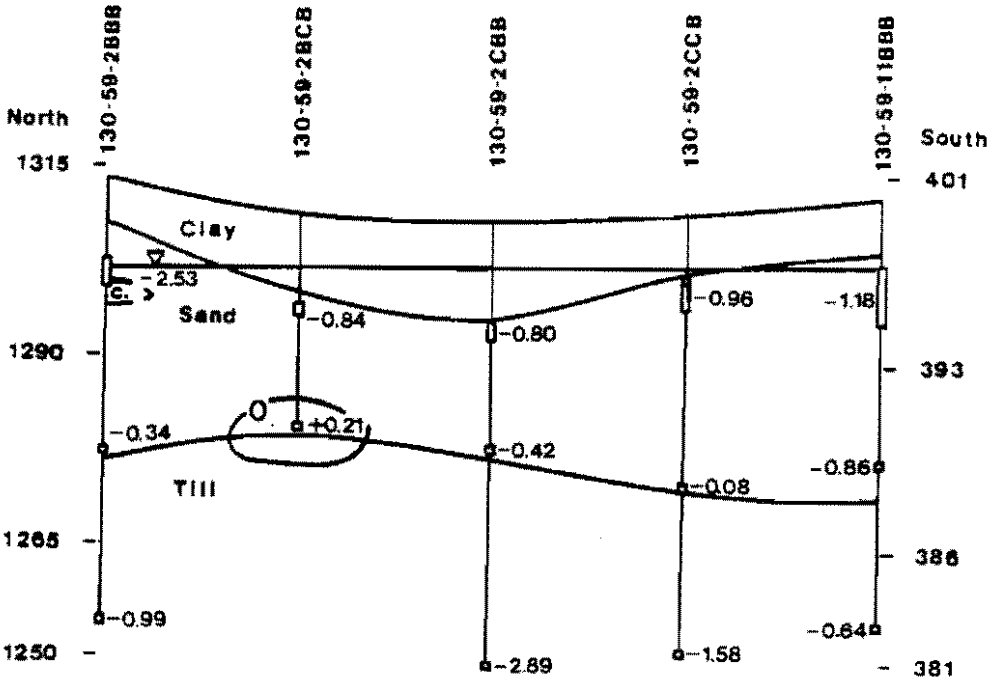

North
1315
1290
1265
1250
130-59-2BBB
130-59-2BCB
130-59-2CBB
130-59-2CCB
130-59-11BBB
South
401
393
386
381
Clay
Sand
Till
-1.12
-1.05
-0.67
-0.64
-1.91
-0.33
-0.14
-0.55
0
+0.55
+0.29
-0.67
-2.48
-0.41
-0.13

Figure 96. Gypsum saturation along the north-south traverse (April, 1984).

Figure 97. Siderite saturation along the north-south traverse (April, 1984).


North
Elev.(ft.)
1315
1290
1265
1250
130-59-2BBB
130-59-2BCB
130-59-2CBB
130-59-2CCB
130-59-11BBB
South
Elev. (m.)
401
393
386
381
Clay
Sand
Till
-1.58
-1.18
-1.85
-1.20
-1.85
-0.09
-0.11
-0.21
-0.42
-0.50
-0.82
-0.41
-0.56
-0.82
Horizontal scale:
feet
metres
0
1000
2000
500
Legend:
lithologic contact
inferred contact
water table
well screen


North
1315
1290
1265
1250
130-59-2BBB
130-59-2BCB
130-59-2CBB
130-59-2CCB
130-59-11BBB
South
401
393
386
381
Clay
Sand
Till
-2.53
-0.84
-0.80
-0.96
-1.18
-0.34
+0.21
-0.42
-0.08
-0.86
-0.99
-2.89
-1.58
-0.64

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